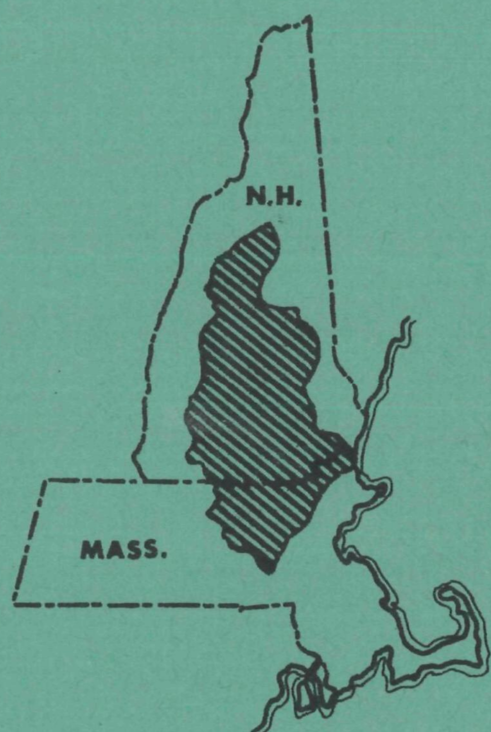
REPORT ON POLLUTION OF THE MERRIMACK RIVER AND CERTAIN TRIBUTARIES —

part II - Stream Studies Physical, Chemical and Bacteriological



U. S. DEPARTMENT OF THE INTERIOR

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

Merrimack River Project - Northeast Region

Lawrence, Massachusetts

August 1966

REPORT ON POLLUTION OF
THE MERRIMACK RIVER
AND CERTAIN TRIBUTARIES
PART II - STREAM STUDIES - PHYSICAL, CHEMICAL & BACTERIOLOGICAL

by

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Federal Water Pollution Control Administration
Northeast Region
Merrimack River Project
Lawrence, Massachusetts

August. 1966

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

INTRODUCTION

In accordance with the written request to the Secretary of Health, Education, and Welfare from the Honorable Endicott Peabody, former Governor of Massachusetts, dated February 12, 1963, and on the basis of reports, surveys or studies, the Secretary of Health, Education, and Welfare, on September 23, 1963, called a conference under the provisions of the Federal Water Pollution Control Act (33 U.S.C. 466 et seq.) in the matter of pollution of the interstate waters of the Merrimack and Nashua Rivers and their tributaries (Massachusetts - New Hampshire) and the intrastate portions of those waters within the State of Massachusetts. The conference was held February 11, 1964, in Faneuil Hall, Boston, Massachusetts. Pollution sources and the effects of their discharges on water quality were described at the conference(1).

ORGANIZATION OF PROJECT

In February 1964, the U. S. Department of Health, Education, and Welfare established the Merrimack River Project to carry out a study in the Merrimack River Basin. The basic objectives were twofold:

1. Evaluation of the adequacy of the pollution abatement measures proposed for the Merrimack River within Massachusetts.
2. Development of adequate data on the water quality of the Merrimack River and its tributaries. Waters in both New Hampshire and Massachusetts were to be studied.

Headquarters for the Project were established at the Lawrence Experiment Station of the Commonwealth of Massachusetts, Lawrence, Massachusetts. The Project became operational July 1, 1964.

During the first year of operation efforts were concentrated primarily in the Massachusetts section of the Merrimack River. Second year studies were mainly of the New Hampshire sections involving suspected interstate pollution, and of the Nashua River.

Prior to initiation of the field studies, a meeting was held among representatives of the Massachusetts Department of Public Health, the R. A. Taft Sanitary Engineering Center and Project personnel concerned with the approach to be used to evaluate the adequacy of the Massachusetts pollution abatement program. It was agreed to use the basic approach used by Camp, Dresser and McKee, Consulting Engineers[2] but with more emphasis on certain variables considered to be weak. In addition, gaps in water quality information, such as the biological condition of the river, were to be filled.

PERSONNEL

Staff members available for all or a major portion of the study included:

Herbert R. Pahren Project Director	Charles D. Larson Chief, Field Operations
Warren H. Oldaker Chief, Laboratory Services	Myron O. Knudson Sanitary Engineer
Donald R. Smith Sanitary Engineer	Howard S. Davis Microbiologist
Alexis A. Burgum Chemist	Patricia M. Akroosh Secretary

The following staff members assisted during a portion of the time:

Fil D. Barrozo Chemist	Irene A. McGravey Chemist
David A. Roussel Engineering Aide	Michael J. Twomey Engineering Aide
Thomas H. Vanderspurt Physical Science Aide	Carl L. Eidam, Jr. Engineering Aide
Anthony J. Razza Engineering Aide	Eva M. Taper Clerk-Stenographer

ACKNOWLEDGEMENTS

Valuable assistance was rendered by a number of agencies, industries, and individuals during the study. Special acknowledgement for important contributions must go to the following:

Massachusetts Department of Public Health, especially Dr. Alfred L. Frechette, Mr. Worthen H. Taylor and Mr. Barnet L. Rosenthal for the use of the office and laboratory space at the Lawrence Experiment Station, and for other supporting services.

New Hampshire Water Pollution Commission

New England Interstate Water Pollution Control Commission

Massachusetts Department of Natural Resources, Division of Marine Fisheries

City of Lowell, Massachusetts, Water Treatment Plant personnel

City of Lawrence, Massachusetts, Water Treatment Plant personnel

Public Service Company of New Hampshire

Avco Corporation, Research and Advanced Development Division

U. S. Department of Interior, Water Resources Division

Communicable Disease Center, U. S. Department of Health, Education, and Welfare

Raritan Bay Project, U. S. Department of the Interior

R. A. Taft Sanitary Engineering Center, U. S. Department of the Interior

STUDY AREA

The Merrimack River Basin, located in central New England, extends from the White Mountains in New Hampshire southward into northeastern Massachusetts. River flow is in a southerly direction through New Hampshire. Upon entering Massachusetts, the Merrimack River turns abruptly east for a distance of about 45 miles and empties into the Atlantic Ocean at Newburyport, Massachusetts. The lower 22 miles of the river are tidal. Lands drained by the Merrimack River consist of 5,010 square miles, of which 3,800 square miles are in New Hampshire and 1,210 square miles lie in Massachusetts. A map of the Merrimack River Basin is shown in Figure 1, located in Appendix G.

Principle streams under study by the Merrimack River Project included the main-stem of the Merrimack River from Franklin, New Hampshire, to the mouth at Newburyport, Massachusetts; the Pemigewasset River; the Souhegan River; and the Nashua and North Nashua Rivers. Tributaries flowing into these streams were also studied.

POPULATION

The 1960 population within the Merrimack River Basin is estimated to be 1,072,000, of which 747,000 are in Massachusetts and 325,000 are in New Hampshire. The population centers, for the most part, are located along the Merrimack River itself. Twelve localities, listed in Table 1, having a population of more than 25,000 account for 53 percent of the total basin population.

TABLE 1

MAJOR COMMUNITIES IN MERRIMACK RIVER BASIN

	Community	Population-1960
New Hampshire	Manchester	88,282
	Nashua	39,096
	Concord	28,991
Massachusetts	Lowell	92,107
	Lawrence	70,933
	Haverhill	46,346
	Framingham	44,526
	Fitchburg	43,021
	Natick	28,831
	Methuen	28,114
	Leominster	27,929
	Lexington	27,691

CLIMATE

Climatic conditions in the Merrimack River Basin vary with the elevation and location relative to the coast. The southeastern part of the watershed near Newburyport, Massachusetts, because of its proximity to the Atlantic Ocean, does not undergo the extremes of temperature and depth of snow of the sections in New Hampshire at higher elevations. Frequent but generally short periods of heavy precipitation are common in the basin.

Precipitation is distributed fairly uniformly throughout the year, as may be seen in Table 2. Two locations, Franklin, New Hampshire, and Lowell, Massachusetts, were selected as typical of the area. Franklin is located at the confluence of the Pemigewasset and Winnepesaukee Rivers; Lowell is located on the Merrimack River. Precipitation records for 1964, when much of the work of the Merrimack River Project was carried out, are presented along with the normal values for each month. Average monthly temperatures are also listed for these two communities.

TABLE 2

CLIMATOLOGICAL DATA

	Precipitation, Inches				Temperature, °F			
	Franklin, N.H.		Lowell, Mass.		Franklin, N.H.		Lowell, Mass.	
	Normal	1964	Normal	1964	Normal	1964	Normal	1964
January	3.30	5.31	4.02	4.06	20.9	22.5	26.7	28.7
February	2.67	1.61	3.16	3.65	22.2	22.2	27.9	26.9
March	3.23	3.83	4.22	3.51	31.3	33.7	36.1	37.5
April	3.47	2.55	3.69	3.03	43.8	43.5	47.5	46.2
May	3.94	1.15	3.31	0.76	55.7	60.1	59.1	61.6
June	3.68	1.59	3.36	1.29	65.1	66.2	68.1	67.7
July	3.65	2.15	3.41	2.57	70.2	71.2	73.6	72.6
August	2.99	3.62	3.52	2.17	67.9	63.9	71.6	66.2
September	3.82	0.55	3.71	2.05	60.2	57.9	63.8	61.7
October	2.99	1.79	3.16	2.78	48.9	48.4	53.2	51.8
November	4.03	4.53	4.18	2.83	37.4	37.7	42.0	42.4
December	3.42	3.52	3.60	4.17	24.5	23.5	30.0	30.0
Annual	41.19	32.20	43.34	32.87	45.7	45.9	50.0	49.4

SOURCES OF POLLUTION

Sewage and industrial wastes contain a variety of obnoxious components which can damage water quality and restrict its use. Oxygen-demanding materials can limit or destroy fish, fish food organisms, and other desirable aquatic life by removing dissolved oxygen from the river. Greasy substances can form objectionable surface scums, settleable solids can create sludge deposits and suspended materials can make once attractive waters appear turbid.

Industrial wastes may also contain additional objectionable chemicals and toxic substances that can kill aquatic life, taint fish flesh, or promote slime growths in the receiving waters. Heat from industrial processes or steam-electric generating plants can magnify the adverse effects of other decomposing wastes and, if excessive, can injure or kill fish and other aquatic life.

Sewage contains astronomical numbers of intestinal bacteria which were released in man's excretions. Some of these, such as the Salmonella bacteria, may be pathogens which can reinfect man with a variety of diseases.

The 5-day biochemical oxygen demand test of sewage and industrial wastes measures the potential of these materials to reduce the dissolved oxygen content of the river waters. The coliform bacteria content of raw and treated sewage indicates the density of sewage-associated bacteria, which may include disease-producing pathogens, discharged to the river. Oxygen-demanding loads are expressed as population equivalents (PE) of 5-day biochemical oxygen demand (BOD), and the bacterial loads are expressed as bacterial population equivalents (BPE) of total coliform bacteria. Each PE or BPE unit represents the average amount of oxygen demand or coliform bacteria normally contained in sewage contributed by one person in one day. (One PE equals one-sixth pound per day of 5-day BOD, and one BPE equals about 250 billion coliform bacteria per day).

The amount of such pollutional components in sewage that can be removed by sewage treatment works depends upon the type and capacity of the plants and the skill of the operators. Types of sewage treatment plants in this area are generally identified as primary or secondary - with or without chlorination.

Primary treatment plants, which consist essentially of settling tanks and sludge digesters, can remove most of the scum and settleable solids, about one-third of the oxygen-demanding materials and approximately 50 per cent of the bacteria. Secondary plants consist of biological treatment units, such as trickling filters, activated sludge or oxidation lagoons. Such plants can remove about 90-95 per cent of the BOD, suspended solids and coliform bacteria. Chlorination facilities for disinfection of properly treated sewage plant effluents can destroy more than 99 per cent of the sewage bacteria. To accomplish these reductions, however, treatment facilities must be properly designed and skillfully operated.

Estimates have been made of the waste discharges to the Merrimack River study area. These estimates, based primarily on surveys taken by the Massachusetts Department of Public Health, the New Hampshire Water Pollution Commission and the National Council for Stream Improvement (of the Pulp, Paper, and Paperboard Industries) are summarized in Table 3.

Total discharges of municipal and industrial wastes to the Merrimack River alone exceed 120 million gallons per day. This volume is exclusive of industrial cooling water.

TABLE 3

ESTIMATED CHARACTERISTICS OF SEWAGE AND INDUSTRIAL WASTES
DISCHARGED TO MERRIMACK RIVER AND TRIBUTARIES WITHIN STUDY AREA

SOURCE	RIVER DISCHARGED TO	TREATMENT AND WASTE REDUCTION MEASURES	POPULATION EQUIVALENTS DISCHARGED		
			BACTERIAL	SUSPENDED SOLIDS	OXYGEN DEMAND
NEW HAMPSHIRE					
Franconia Paper Corp., Lincoln*	Pemigewasset East Branch	None—except that bark is burned	—	200,000	400,000
Franklin	Winnipesaukee	None	4,500	4,500	4,500
Boscawen	Contoocook	None	400	400	400
Brezner Tanning Corp., Boscawen	Contoocook	None	—	2,500	1,500
Concord (Penacook Village)	Merrimack	None	2,000	50,000	32,000
Penacook Fibre Co., Penacook	Contoocook	Wastes recirculated	—	230	200
Concord	Merrimack	None	24,000	24,000	24,000
Pembroke	Merrimack	None	1,800	1,800	1,800
Allenstown	Merrimack	None	1,250	1,250	1,250
Hooksett	Merrimack	None	1,000	1,000	1,000
French Bros. Beef Co., Hooksett	Merrimack	None	—	380	1,080
State Industrial School	Merrimack	None	300	300	300
Manchester	Merrimack	None	72,500	72,500	72,500
M. Schwer Realty Co., Manchester	Merrimack	None	—	650	6,500
Granite State Packing Co., Manchester	Merrimack	None	—	19,000	46,000
MKM Knitting Mills Inc., Manchester	Merrimack	None	—	400	4,000
Manchester Hosiery Mills, Manchester	Merrimack	None	—	10	50
Seal Tanning Co., Manchester	Merrimack	None	—	8,000	5,000
Stephens Spinning Co., Manchester	Merrimack	None	—	400	4,000
Waumbec Mills Inc., Manchester	Merrimack	None	—	700	7,200
Foster Grant Co., Manchester	Merrimack	None	—	110	15,000
Merrimack (Reeds Ferry Village)	Merrimack	None	200	200	200

*Also discharges materials that cause a color problem in receiving stream.

TABLE 3 (Continued)

ESTIMATED CHARACTERISTICS OF SEWAGE AND INDUSTRIAL WASTES
DISCHARGED TO MERRIMACK RIVER AND TRIBUTARIES WITHIN STUDY AREA

SOURCE	RIVER DISCHARGED TO	TREATMENT AND WASTE REDUCTION MEASURES	POPULATION EQUIVALENTS DISCHARGED		
			BACTERIAL	SUSPENDED SOLIDS	OXYGEN DEMAND
Merrimack	Merrimack	None	200	200	200
Merrimack Leather Co., Merrimack	Souhegan	None	—	12,000	7,500
New England Pole and Wood Treating Corp., Merrimack	Merrimack	Phenol recovery	—	—	—
Wilton	Souhegan	None	1,000	1,000	1,000
Hillsborough Mills, Wilton	Souhegan	None	—	7,000	3,500
Milford	Souhegan	None	3,000	3,000	3,000
Granite State Tanning Co., Nashua	Nashua	Settling	—	12,000	16,500
Sanders Associates, Nashua*	Nashua	None	—	850	1,200
Johns-Manville Co., Nashua	Nashua	Settling	—	350	220
Nashua	Merrimack	Partly raw, partly primary, partly secondary	28,500	28,200	30,300
Hampshire Chem. Co., Nashua	Merrimack	Ammonia recovery, lagoon	—	—	—
Hudson	Merrimack	None	600	600	600
Derry	Beaver Brook	Secondary	40	600	400
Salem	Spicket	Secondary with Cl_2	10	150	100
TOTAL NEW HAMPSHIRE			141,300	454,280	693,000

*Plating baths periodically dumped. Probably contain copper and cyanide.

TABLE 3 (Continued)

ESTIMATED CHARACTERISTICS OF SEWAGE AND INDUSTRIAL WASTES
DISCHARGED TO MERRIMACK RIVER AND TRIBUTARIES WITHIN STUDY AREA

SOURCE	RIVER DISCHARGED TO	TREATMENT AND WASTE REDUCTION MEASURES	POPULATION EQUIVALENTS DISCHARGED BACTERIAL	SUSPENDED SOLIDS	OXYGEN DEMAND
MASSACHUSETTS					
Cushing Academy	Phillips Brk.	Secondary with Cl_2	3	45	30
State Hospital, Gardner	Whitman	Secondary with Cl_2	16	80	80
Weyerhaeuser Paper Co., Fitchburg	North Nashua	Savealls, wastes recirculated, starch substitution, settling	—	184,600	39,650
Fitchburg Paper Co., Fitchburg	North Nashua	Savealls, wastes recirculated, retention aids	—	108,200	37,060
Simonds Saw and Steel Co., Fitchburg	North Nashua	None	—	—	5,800
Falulah Paper Co., Fitchburg	North Nashua	Wastes recirculated, chemical precipitation, vacuum filtration of sludge	—	115,400	27,940
Fitchburg	North Nashua	Inadequate secondary	18,900	20,700	19,500
Mead Corp., Leominster	North Nashua	Starch substitution, wastes recirculated	—	30,300	5,700
Foster Grant Co., Leominster	North Nashua	Lagoon	—	16,600	2,500
Leominster	North Nashua	Partly secondary, partly raw	3,000	5,200	12,140
Atlantic Union College, Lancaster	North Nashua	Partly primary, partly secondary	210	210	280
Lancaster	Nashua	None	150	150	150
Blackstone Mills, Inc., Clinton	South Nashua	None	—	—	150
Clinton	South Nashua	Secondary	1,300	1,560	1,040
Girls Industrial School	Nashua	Secondary	15	18	18
Ayer	Nashua	Secondary	375	750	500
Shirley	Nashua	None	100	100	100
Hollingsworth and Vose Co., Groton	Nashua	Settling, wastes recirculated	—	1,470	6,650

Supplemental Data: Borden Chemical Co., Leominster, Massachusetts, having no treatment measures, discharges suspended solids population equivalents of 2,000 and oxygen demand population equivalents of 11,000 to the North Nashua River.

TABLE 3 (Continued)

ESTIMATED CHARACTERISTICS OF SEWAGE AND INDUSTRIAL WASTES
DISCHARGED TO MERRIMACK RIVER AND TRIBUTARIES WITHIN STUDY AREA

SOURCE	RIVER DISCHARGED TO	TREATMENT AND WASTE REDUCTION MEASURES	POPULATION EQUIVALENTS DISCHARGED		
			BACTERIAL	SUSPENDED SOLIDS	OXYGEN DEMAND
Groton Leather Board Co., Groton	Nashua	Settling, wastes recirculated	—	5,880	2,120
Groton School	Nashua	Secondary	8	10	10
St. Regis Paper Co., Pepperell	Nashua	Savealls, wastes recirculated	—	64,700	16,200
Pepperell	Nashua	None	200	200	200
Southwell Combing Co., Chelmsford*	Merrimack	Grease recovery	—	30,800	22,100
H. E. Fletcher Co., Chelmsford	Merrimack	None	—	2,940	150
Gilet Wool Scouring Corp., Chelmsford**	Stony Brook	None	—	13,600	19,700
J. P. Stevens & Co., Dracut	Beaver Brook	None	—	—	850
Dracut	Beaver Brook	None	1,000	1,000	1,000
Chemical Mfg. Co., Ashland	Sudbury	Neutralization, sand filter	—	—	500
General Electric Co., Ashland	Sudbury	Neutralization, settling, Cl_2, alkaline Cl_2 of CN	—	150	—
Marlborough	Sudbury	Secondary with Cl_2	130	900	600
Roxbury Carpet Co., Framingham***	Sudbury	None	—	—	—
Westborough	Assabet	Inadequate secondary	300	1,760	2,900
Hudson Combing Co., Hudson	Assabet	Settling & lagoons	—	1,000	950
Hudson	Assabet	Inadequate secondary with Cl_2	70	1,080	720
Maynard	Assabet	Inadequate secondary	510	1,020	680
Mass. Reformatory	Assabet	Secondary	40	50	50
Concord	Concord	Secondary	180	225	225
Billerica House of Correction	Concord	Secondary with Cl_2	4	50	35
Billerica	Concord	Partly raw, partly secondary with Cl_2	320	400	375
No. Billerica Co., Billerica	Concord	None	—	1,410	5,530

*Also discharges 2,380 pounds of grease per day.
**Also discharges 3,120 pounds of grease per day.
***Periodic dumping of dye.

TABLE 3 (Continued)

ESTIMATED CHARACTERISTICS OF SEWAGE AND INDUSTRIAL WASTES
DISCHARGED TO MERRIMACK RIVER AND TRIBUTARIES WITHIN STUDY AREA

SOURCE	RIVER DISCHARGED TO	TREATMENT AND WASTE REDUCTION MEASURES	POPULATION EQUIVALENTS DISCHARGED		
			BACTERIAL	SUSPENDED SOLIDS	OXYGEN DEMAND
Lowell Rendering Co., Billerica	Concord	Grease recovery	—	5,300	11,000
Raytheon Co., Tewksbury	Shawsheen	Settling, sand filters & Cl_2	—	100	200
Ames Textile, Lowell	Merrimack	None	—	18	1,850
Vertipile Inc., Lowell	Merrimack	Centrifuges	—	210	2,220
Jean-Alan Products Co., Lowell	Merrimack	None	—	2,040	940
Robinson Top & Yarn Dye Works, Lowell	Merrimack	None	—	8	1,100
Byfield Felting Co., Lowell*	Merrimack	None	—	—	12
United Elastic Co., Lowell	Merrimack	None	—	18	120
Vogue Silver Co., Lowell	Merrimack	None	—	60	180
Middlesex Worsted Spinning Co., Lowell	Merrimack	None	—	18	1,550
Suffolk Knitting Co., Lowell	Merrimack	None	—	1,270	5,700
Commodore Foods Inc., Lowell	Merrimack	None	—	4,300	4,400
Lowell	Merrimack	None	90,000	95,000	112,000
U. S. Veterans Hospital, Bedford	Shawsheen	Tertiary with Cl_2	—	20	15
U. S. Army Housing, Bedford	Shawsheen	Primary	50	50	50
State Hospital, Tewksbury	Shawsheen	Secondary with Cl_2	26	130	130
Andover	Shawsheen	Partly raw, partly secondary	8,400	12,600	8,400
Mead Corp., Lawrence	Merrimack	Wastes recirculated, Savealls	—	22,500	9,300
Oxford Paper Co., Lawrence	Merrimack	Wastes recirculated, savealls chemical treatment	—	51,100	32,100
Agawam Dye Works Inc., Lawrence	Merrimack	None	—	—	705

*Discharges batches of acid wastes.

TABLE 3 (Continued)

ESTIMATED CHARACTERISTICS OF SEWAGE AND INDUSTRIAL WASTES
DISCHARGED TO MERRIMACK RIVER AND TRIBUTARIES WITHIN STUDY AREA

SOURCE	RIVER DISCHARGED TO	TREATMENT AND WASTE REDUCTION MEASURES	POPULATION EQUIVALENTS DISCHARGED		
			BACTERIAL	SUSPENDED SOLIDS	OXYGEN DEMAND
Merrimack Paper Co., Lawrence	Merrimack	Wastes recirculated	—	5,100	4,400
Lawrence Wool Scouring Co., Lawrence*	Merrimack	Grease recovery	—	13,500	9,180
Loom Weave Corp., Lawrence	Merrimack	None	—	440	1,760
Lawrence	Merrimack	None	70,000	149,000	120,000
Western Electric Co., North Andover	Merrimack	Primary, neutralization	—	400	135
North Andover	Merrimack	None	9,000	18,800	13,600
Methuen	Merrimack	None	17,000	18,000	23,800
Continental Can Co., Haverhill	Merrimack	Savealls, wastes recirculated	—	77,000	47,000
Hoyt & Worthen Tanning Corp., Haverhill	Merrimack	Grease and oil recovery	—	7,000	4,400
Cowan & Shain Inc., Haverhill	Merrimack	None	—	10	790
C. F. Jameson Co., Haverhill	Merrimack	None	—	60	60
Haverhill	Merrimack	None	44,000	71,000	50,000
Groveland	Merrimack	None	1,000	1,000	1,000
Amesbury Fibre Corp., Amesbury	Merrimack	Wastes recirculated, savealls	—	6,820	3,530
Merrimack Hat Co., Amesbury	Merrimack	None	—	235	1,120
Amesbury Metal Products Co., Amesbury	Merrimack	None	—	—	—
Amesbury	Powwow	None	7,200	14,000	11,000
Newburyport	Merrimack	Primary with Cl_2	140	7,700	10,000
Salisbury	Merrimack	Inadequate primary	1,250	1,100	1,620
TOTAL MASSACHUSETTS			274,897	1,198,465	729,490
TOTAL NEW HAMPSHIRE			141,300	454,280	693,000
TOTAL BOTH STATES			416,197	1,652,745	1,422,490

*Also discharges 860 pounds of grease per day.

WATER USES

PRESENT USES

Municipal Use

At present there are two cities, Lowell and Lawrence, that are using the Merrimack River as a source of municipal water supply. Since 1963 the river has been the principal source of water supply for approximately 65,000 persons in the City of Lowell, Massachusetts. Lowell's water intake is located eleven miles below Nashua, New Hampshire, and seven miles below the New Hampshire-Massachusetts state line. Lawrence, Massachusetts, which has been using the Merrimack as a source since 1893, is presently supplying water to 90,000 people in Lawrence and neighboring Methuen. The water intake is located nine miles downstream from Lowell.

As populations rapidly increase in many of the cities and towns along the Merrimack River, additional municipalities may need to use this convenient source of water supply. Chelmsford, Tyngsboro, Andover, North Andover, Tewksbury and West Newbury, Massachusetts, have already been mentioned as potential users of the Merrimack, not to mention Concord, Manchester and Nashua, New Hampshire.

In addition, several tributaries are now being used. Billerica, Massachusetts, uses the Concord River as its source of municipal water supply, having completed a new water treatment plant for this purpose in 1955. Nashua, New Hampshire, utilizes part of the flow of the Souhegan River, and Concord, New Hampshire, obtains water from the Soucook River.

Additional use of tributaries is being considered by several cities and towns. These include Burlington, Massachusetts, (the Shawsheen River) and Concord, New Hampshire, (the Contoocook River).

Industrial Use

In 1954 approximately 185 million gallons of water per day were taken from the Merrimack River for industrial use in the major industrial centers of Manchester, New Hampshire, and Lowell, Lawrence and Haverhill, Massachusetts[3]. Another 27 million gallons per day were taken from the North Nashua River by Fitchburg industries. Since then industrial water us has probably been reduced because a number of the major water-using industries have moved out of the basin.

About half of the industrial water use in 1954 was for cooling purposes, which requires no processing. Some industries do use Merrimack River water for processing, but the water quality is not satisfactory and sand filters are needed to precondition it. Feeder streams are also used for industrial water supplies. Nashua River water is used for industrial processing in a number of instances. Where preconditioning is necessary, facilities ranging from sand filters to ion exchange processes are used.

The Merrimack River is used for hydroelectric power to a large extent. On the Merrimack below Franklin, New Hampshire, there are five utility plants and thirteen privately-owned industrial developments, with total capacities of 28,670 and 22,320 kilowatts, respectively[4].

These 18 plants utilize 177 feet of a total fall of 254 feet. Canal systems at Lowell and Lawrence, Massachusetts, divide the use of water among several plants at each location. On weekends, the Merrimack River flow below several of the dams is drastically reduced as a result of "stacking" practices. This two-day reduction in flow seriously affects the capacity of the river to assimilate wastes during July, August and September.

Agricultural Use

Merrimack River water is used for irrigation of truck crops from Franklin, New Hampshire, to below Haverhill, Massachusetts. Between Manchester, New Hampshire, and the state line, there are several hundred acres of truck crops along the banks of the Merrimack River.

Fish and Wildlife Use

According to the U. S. Fish and Wildlife Service, parts of the Merrimack River in New Hampshire possess an outstanding fishery. However, there is public aversion to using fish caught from the river for food because of the raw sewage emptied into the river. Consequently, any fishing done there is merely for sport. Fabulous potential exists for the fishing that may materialize if the pollution is cleaned up. Rainbow and brook trout are planted in approximately 155 New Hampshire rivers and brooks that are tributary to the Merrimack River, excluding tributaries of Lake Winnipesaukee.

The Merrimack River, between the Nashua River and the state line, contains the following fish species in large numbers: yellow perch, red-breasted sunfish, pumpkinseed, large-mouthed bass, eastern chain pickerel, northern yellow bullhead, northern common bullhead, eastern golden shiner, eastern common shiner, fallfish, long-nosed dace, eastern black-nosed dace and eastern common sucker.

The Commonwealth of Massachusetts has estimated that sport fishermen spent over $1,000,000 in total expenses while fishing in the Merrimack River estuary in 1964[5]. The value of an industry of this magnitude to the cities and towns in the vicinity of the Merrimack River estuary is obviously tremendous. However, the polluted condition of the river prevents this revenue source from reaching its maximum benefit to the local communities. This sport industry is primarily dependent upon striped bass, mackerel and blackback flounder fisheries and offshore ground fishery. Commercial value of the estuary is also severely reduced due to pollution. Since 1926 the shellfish beds in the estuary of the Merrimack River have been closed to harvest. In certain small sections shellfish can be taken and treated in the shellfish depuration plant at Newburyport. Due to gross pollution, largely as the result of sewage discharged to the river by neighboring communities, the commercial value of the soft shell clam was only $14,000 of a potential $1,000,000 harvest in 1964[5].

Prior to construction of the dams on the lower Merrimack, hundreds of thousands of anadromous fish were caught annually in the Merrimack River. The most important species included salmon, shad, alewives and smelt. The Merrimack River, once famous for its salmon run, hasn't seen a salmon in almost fifty years. Their disappearance is attributed mainly to dams and pollution.

According to the U. S. Fish and Wildlife Service, the present shad run into the Merrimack is small, because the only area available for spawning, the lower section of the river, is heavily polluted. Even though the fish can ascend the fishway in the Essex Dam at Lawrence, they can only proceed upstream to the Pawtucket Dam at Lowell, which is completely impassable. The number of shad annually ascending the Lawrence fishway is from 1,500 to 3,000 fish. Fishing for shad in the lower river is sporadic, and in some years there is none at all. In 1960 no fish were reported taken.

Because of the polluted conditions in the Nashua River, it is not used for fishing, although it is populated by various types of coarse fish in the lower section.

The tidal marsh and mud flat complex in the Newburyport-Amesbury area is a large important waterfowl area. Another important waterfowl area is the Nashua River Basin, particularly in the Lancaster-Bolton, Massachusetts, region.

Recreational Use

Water-oriented recreational activity has been increasing rapidly on a national scale, especially near centers of population. However, a similar increase has not been possible in the Merrimack River Basin because of its polluted condition. The U. S. National

Park Service in 1954 estimated that tangible benefits of 15 million dollars could be added annually to the economy of an unpolluted Merrimack River Basin by visitor usage(3). Highly significant intangible benefits would also be involved. No doubt the benefits would be even greater today as a result of the increased pressure for recreation.

The Merrimack River is used for boating and water skiing above Manchester, Lowell and Lawrence, and in the tidewater near its mouth. Ski clubs have been formed by people with this mutual interest, and ski jumps are provided for members. For the past several years, the Eastern Stock Outboard Boat Racing Championships have been held in the Merrimack River above Lowell. Other races have taken place in Haverhill and Lowell since the mid-1950's, indicating the popularity of the river for boating. In the Nashua River, there is a small amount of boating in the reservoir above Pepperell; the Concord River is utilized for this purpose in Billerica and Concord.

For several years, Lowell provided a public bathing beach and a change house along the Merrimack, upstream of the city. This facility was closed in 1965 due to pollution. No other public bathing facilities exist on the Merrimack River at this time, although the City of Concord, New Hampshire, has considered converting the present Sewells Falls power generating station and surrounding land to a recreational area.

Swimming takes place to a limited degree at several other points on the river, notably at Hooksett and Manchester, New Hampshire, and Tyngsboro; Lowell, Lawrence and Newburyport, Massachusetts.

FUTURE USES

Municipal Use

As the population of the river basin increases, more and more communities will be needing a water supply of sufficient volume. Such sources will not be available at "remote locations" due to their scarcity, irregular flow, and development cost. The most logical source becomes the Merrimack River, which is already used as a water supply by Lowell and Lawrence, and under consideration by nine other communities.

After waste treatment plants are in operation, benefits to the communities using the river for a water supply would include reduced taste and odor problems, a water that has a greater microbiological safety factor, and reduced costs of water plant operation. For the cities of Lowell and Lawrence, it is estimated that a minimum yearly savings in chemicals of $8,300 could be realized if adequate pollution abatement facilities were in operation.

Industrial Use

With adequate waste treatment, the cities along the river would offer several reasons for attracting new industry. These would include a bountiful source of good quality water and adequate recreation facilities for employees. Savings to the industries would result from reduced pre-conditioning, corrosion, scale and operating costs.

Agricultural Use

Following construction of adequate waste treatment facilities irrigation water would have a lower bacterial density, resulting in a reduced health hazard.

Fish and Wildlife Use

The U. S. Fish and Wildlife Service has indicated that it would be economically feasible to reintroduce salmon and other anadromous fishes to the Merrimack River. Indications are that the number of fishermen in the United States spend $10.00 per fishing trip, and that their numbers will triple between 1960 and 2000. The main stem of the Merrimack River could support an additional 290,000 man-days of fishing per year.

Proper control of pollution would bring full realization of the true fish and wildlife potential of the streams. The entire Merrimack Basin lies within easy reach of highly-populated urban areas. By the year 2000, approximately 3,000,000 of the projected New England population of 17 million people will fish. An estimated 800,000 hunters will live in the area by this date. The Merrimack River would provide many additional fishing and hunting sites for these people.

The Commonwealth of Massachusetts has estimated that the annual harvest of soft shell clams is only one-twentieth of what it could be if pollution was adequately removed from the river. The yearly commercial value of soft shell clams could be $300,000 to $1,000,000.

Recreational Use

Perhaps the most significant advantage from adequate treatment would be in the area of recreation. The Northeastern states have 25 per cent of the population of the country but only 4 per cent of its recreational acreage. Providing reasonable access to the out-of-doors for large concentrations of population will become one of the Northeast's central problems in the next forty years. At the center of concern will be the day and week-end needs of metropolitan residents. With some 10.5 million people within an easy day's drive of the Merrimack River, and an additional 6.5 million expected by the year 2000, the need is easily recognized.

Recent statistics indicate that 41 per cent of the population prefers water-based recreational activities, and it is conservatively estimated that it spends $8.00 per person per day for food, lodging, transportation and miscellaneous items.

The opportunity for boating, swimming and other water related sports would be one benefit of a clean Merrimack River. The many visitors attracted to the region for recreational purposes would be adding millions of dollars to the local economy. However, it has been found in other areas of the United States that, in terms of dollar volume, the increase in county revenues that flows from a rise in value of taxable property is the most important result of the coming of recreation(6).

INCOME LOSS DUE TO POLLUTION

For the Merrimack River Basin, the total minimum lost monetary value of potential resources is estimated to be $37,000,000 for the year

1966. Although this value is for the entire valley, the major loss occurs on the main stem of the Merrimack and Nashua Rivers. The breakdown of lost resources is shown in Table 4.

TABLE 4

1966 INCOME LOSS DUE TO POLLUTION

INCOME SOURCE	INCOME LOST—1966
Commercial Values of Estuary	$ 300,000
Recreation Visitor Income	21,300,000
Increased Property Value	9,100,000
Increased Tax Revenues	5,500,000
Miscellaneous	800,000
Total Income Loss	$37,000,000

The estimate of loss of the commercial value of the estuary was obtained from Commonwealth of Massachusetts studies(5). It was estimated that "...approximately $300,000 worth of clams could be harvested annually...and that...the total value could well exceed $500,000 and might approach $1,000,000 annually." The 1964 harvest was estimated at $14,000.

For 1952 the New England-New York Inter-Agency Committee report(3) estimated that the "...total visitor use of the resources within the basin would approximate 2,800,000 annually...an increase of 1,000,000 over present use. The additional use could be expected to increase total spending in connection with recreation to about $60,000,000, an increase of $15,000,000 over present estimated expenditures." Using the estimated $15,000,000 and applying a rate of 3 per cent increase per year during the period 1952 to 1966, the value is estimated to be $21,300,000 for 1966.

From experiences in other parts of the country(6), it was found that the increased land value and associated tax revenue was one of the most significant local benefits of added recreational opportunities. In order to evaluate the recreational benefit, it was estimated that the total effective recreational land immediately benefitted would equal the area immediately abutting the Merrimack and Nashua Rivers. The selection of this area is based upon its presence in an area lacking recreational facilities, closeness to large metropolitan populations, and present severity of pollution. In addition to the above mentioned area, additional recreational use would be made available on the Pemigewasset, Souhegan and a number of other rivers and streams in the basin. The total river mileage of the Merrimack and Nashua Rivers is 173 miles. Total river bank footage available is, thus, 1,830,600 feet. A minimum value increase of $50 per foot is assumed. In comparison, current lake front property on Lake Winnipesaukee is estimated at $1,200 to $2,200 per foot of lake frontage. Total increase in value is, then, estimated to be $91,400,000. It is further estimated that developments constructed on the land would equal the increased land value, making the total increased value $182,800,000. This value was pro-rated over a 20 year period, so that each year would have a value of $9,100,000.

In order to determine the tax revenue available from the recreational use, property tax was considered only. The current rate of tax revenue in the basin is approximately $30 per $1,000 per year, or 3 per cent. Lost tax revenue on the value of land and buildings amounts to $5,500,000 per year.

Miscellaneous benefits could be realized from such items as reduced water treatment costs for both municipalities and industries, reduced operating expenses for domestic and industrial appliances using water, and reduced laundering costs. These are estimated at $800,000 per year.

The total figure is considered to be a minimum value, and a detailed economic survey would include many additional factors such as:

1. the use of the shllfish market factor, which considers the value added in preparing the shellfish for purchase by the consumer (about five times the $300,000 to $1,000,000 received by the diggers),
2. a more recent projection of recreational visitor use, since recreational use has increased about 125 per cent since 1952, and is expected to triple by the year 2000,
3. an evaluation of increased values for those lands not directly on the river banks, and a value that is higher and more reasonable than the $50 per foot used, and
4. an estimation of construction cost and increased value of buildings on lands probably would be nearer to 3 times the land value instead of being the same.

It is estimated that such a survey would indicate a loss in the range of 60 to 70 million dollars a year instead of 37 million.

The value of recreation to the local area can be measured by another indicator. It has been estimated(7) that "if the community can attract a couple of dozen tourists a day throughout the year, it could be economically comparable to acquiring a new manufacturing industry with an annual payroll of $100,000."

When one considers that pollution conservatively costs the local communities in the Merrimack Basin 37 million dollars a year, then a pollution abatement program costing 100, 150 or even 200 million dollars that can be repaid in less than 6 years, is not prohibitive even on a local basis. The construction of such facilities is not only necessary to protect the health and welfare of the public, but mandatory from an economic viewpoint.

TIME OF STREAM TRAVEL

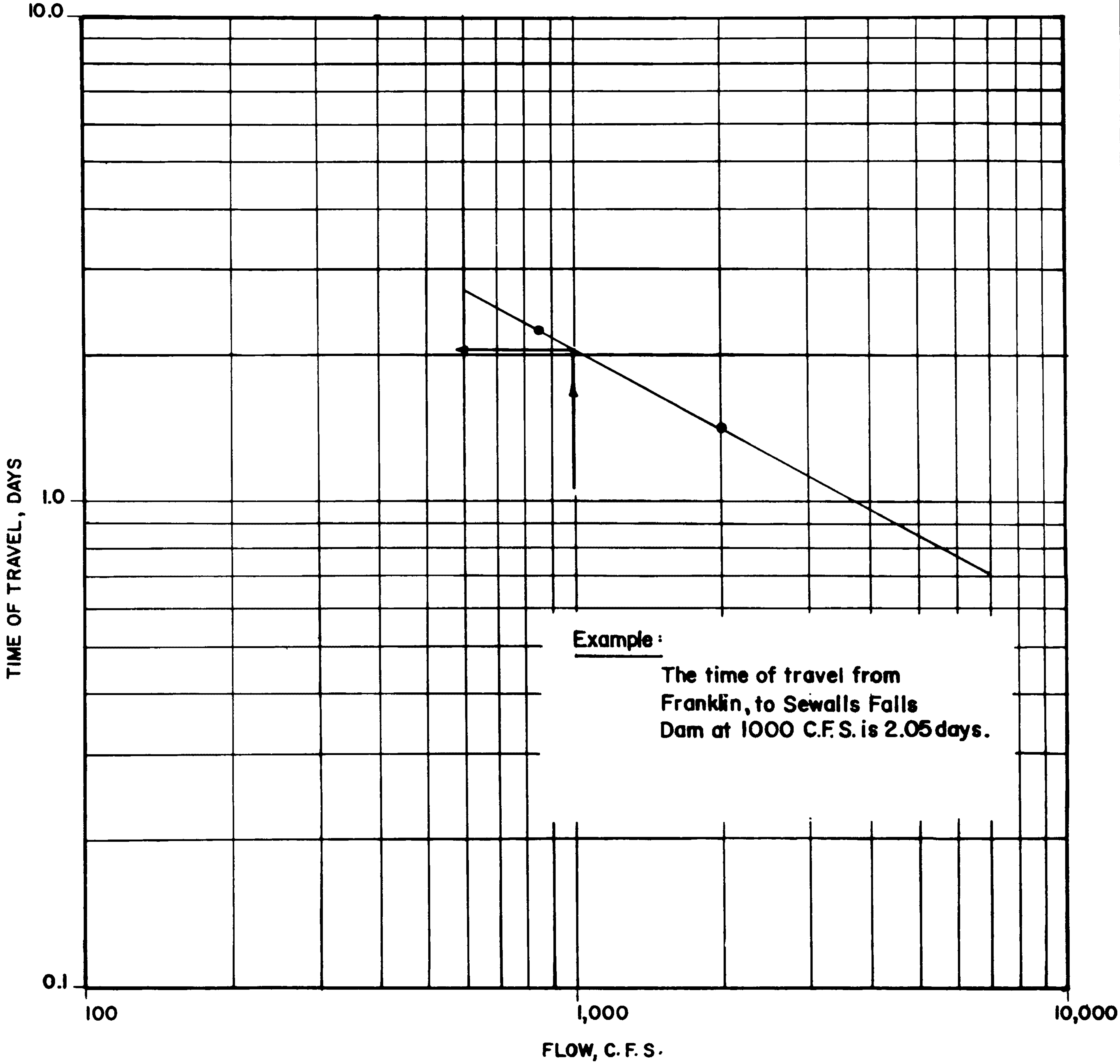
Rhodamine B dye and a fluorometer with a continuous flow cell were used to determine the time of stream travel of the Merrimack River and selected tributaries. When added, a homogeneous mass of dye was found in the vertical plane of the Merrimack River, indicating that it was well mixed. In the horizontal plane, the center of the river channel gave the most consistent results.

Average daily flow in the various reaches of the river was determined from the U. S. Geological Survey gaging station records and records maintained by the Public Service Company of New Hampshire at various power facilities.

Time of travel was calculated from the time required for the peak concentration of dye to pass each key point and from the average daily river flow between points. Data were obtained from the same section of the river at various flows. The results were plotted on log-log graph paper. In the tidal section of the Merrimack River, the net forward velocity of the dye was used.

The time of travel relationship to flow for the Merrimack River from Franklin, New Hampshire, to Newburyport, Massachusetts, appears in Figures 2 through 10. Figures 11 through 14 give the graph of time of travel versus river mile from Franklin to Newburyport. Time of travel graphs for the Souhegan River are presented in Figures 15, 16 and 17. This family of curves represents the range of flows for which time of travel results were obtained.

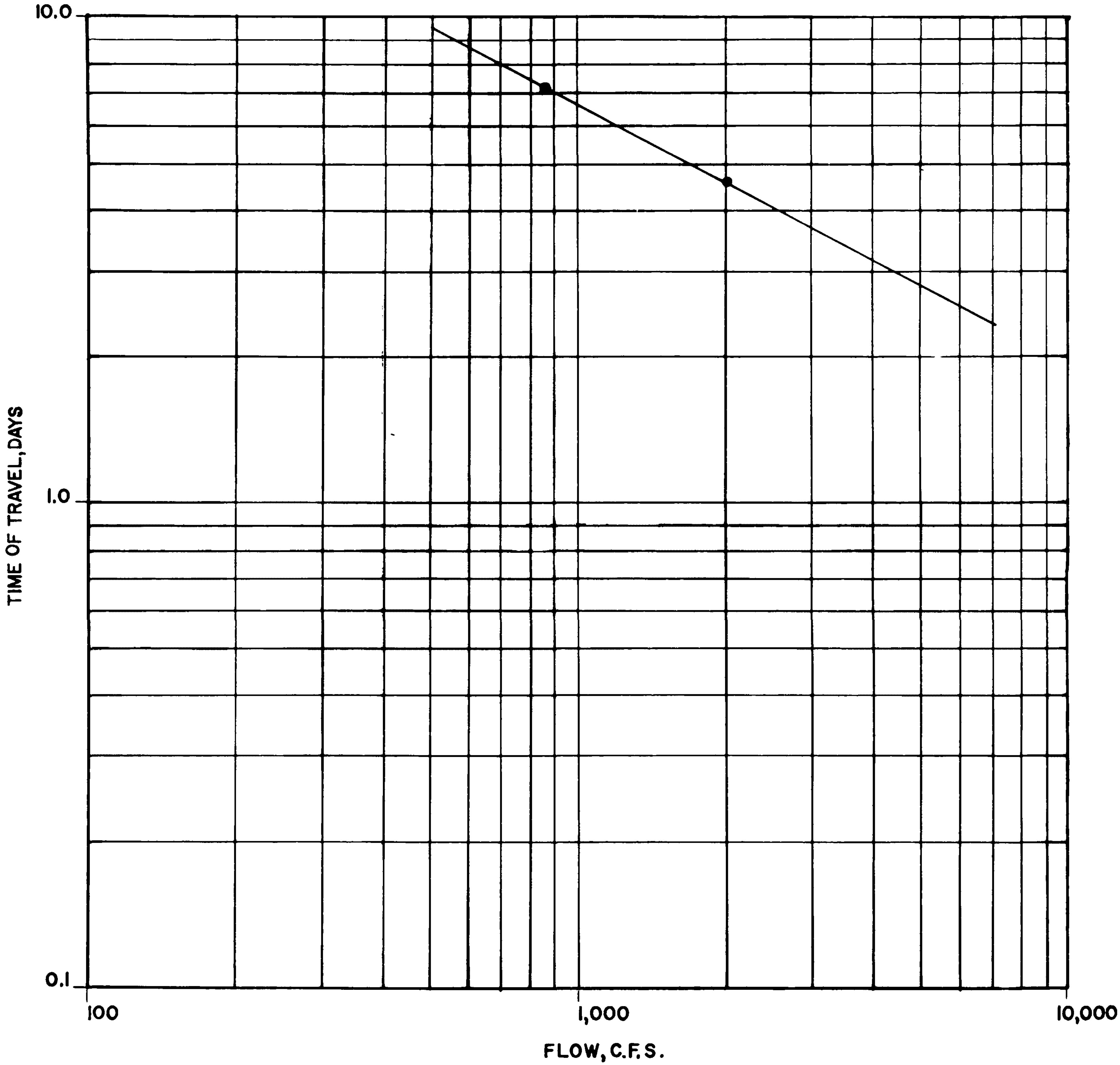
The following is an example of the use of the curves. To determine the time of travel at 1,000 cfs from river mile 54.55, Nashua, New Hampshire, to the Lowell water intake, river mile 43.47, use Figure 12. The time value at river mile 54.55 of 2.15 days is subtracted from the time value at river mile 43.47 of 4.25 days, yielding the time of travel of 2.10 days at 1,000 cfs from Nashua to the Lowell water intake.



MERRIMACK RIVER

TIME OF TRAVEL VS. FLOW - FRANKLIN, N.H. TO SEWALLS FALLS DAM

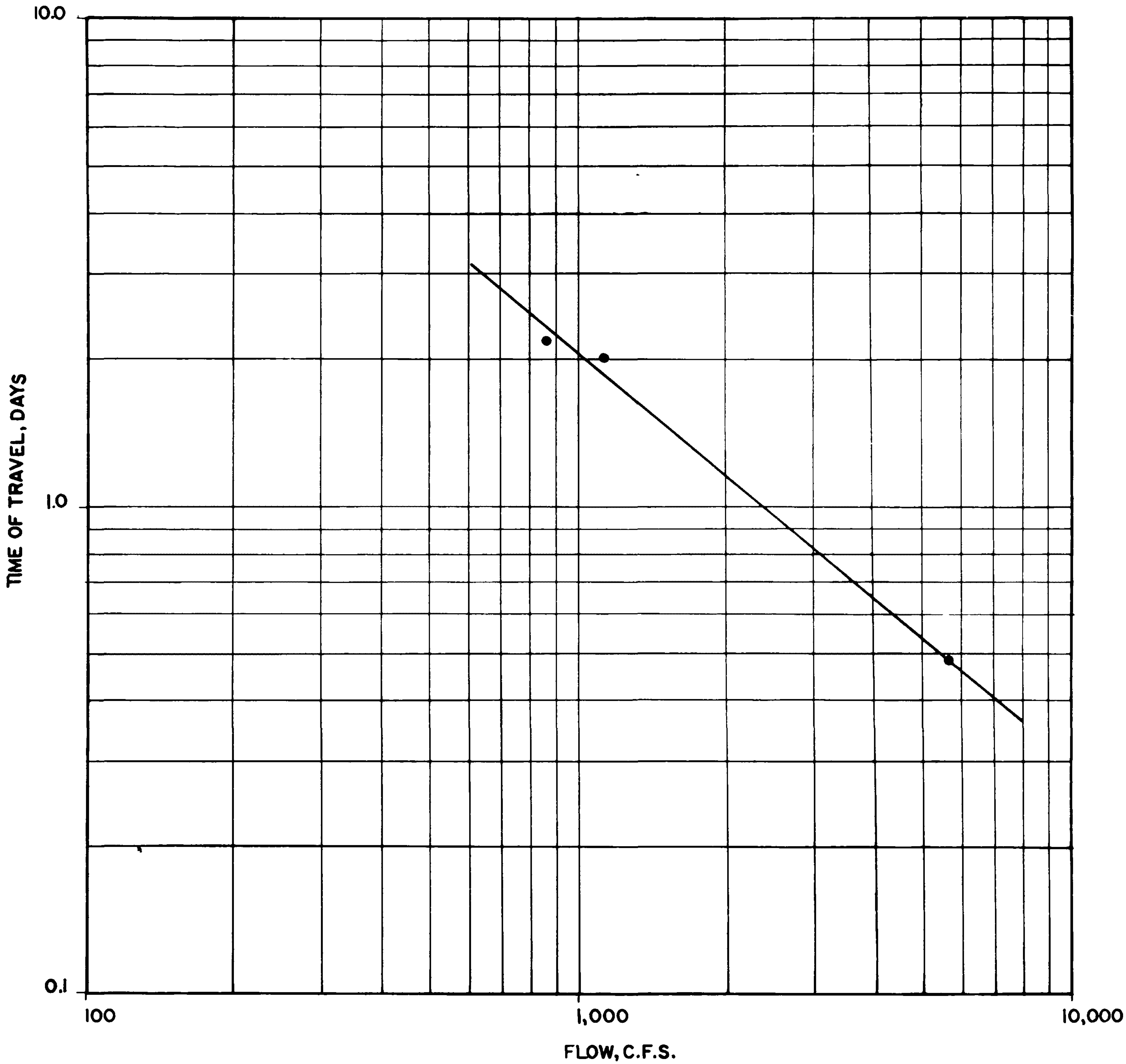
FIGURE 2



MERRIMACK RIVER

TIME OF TRAVEL VS. FLOW - SEWALLS FALLS DAM TO RT. 3 BRIDGE, CONCORD

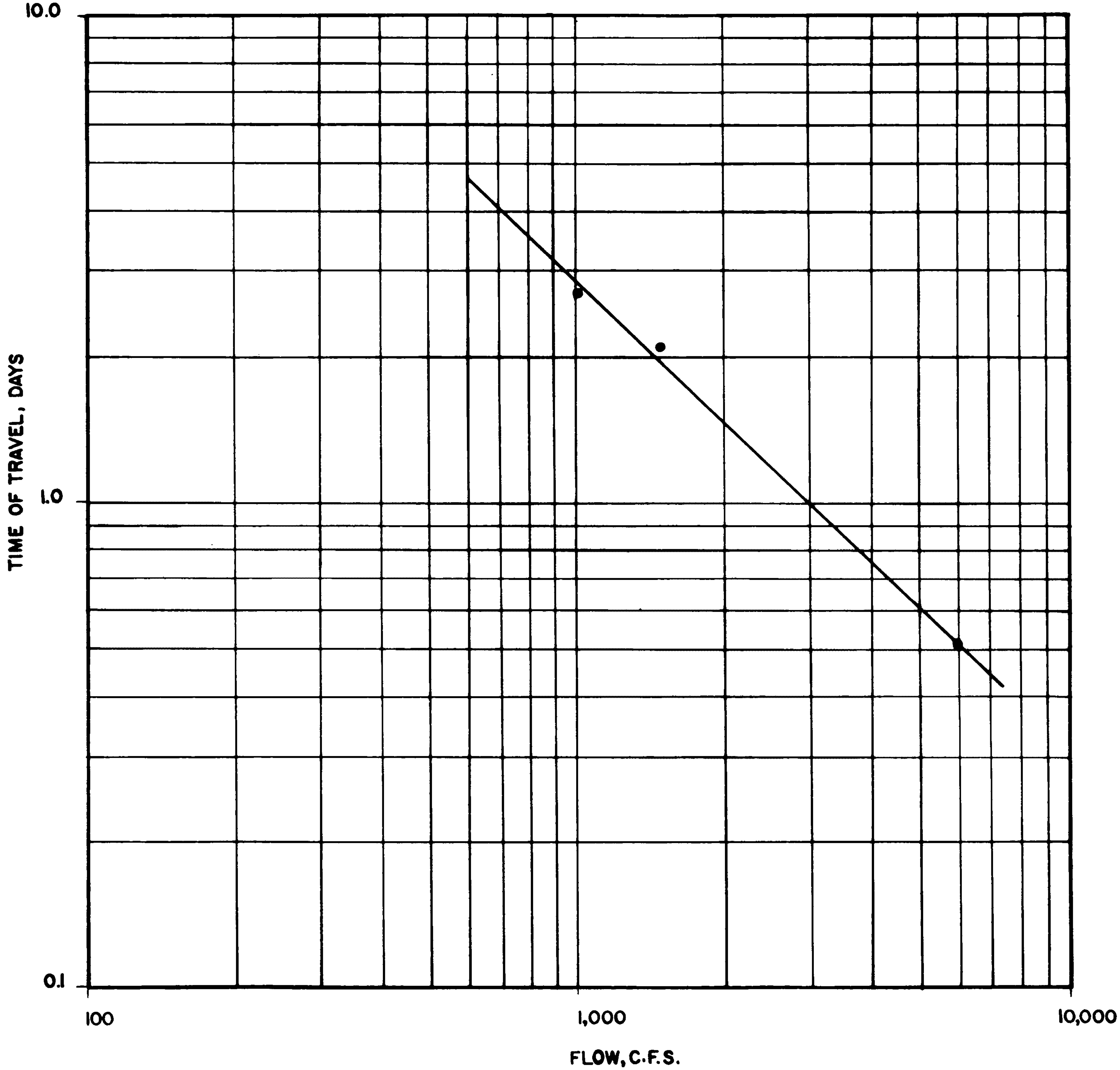
FIGURE 3



MERRIMACK RIVER

TIME OF TRAVEL VS. FLOW - RT. 3 BRIDGE, CONCORD TO HOOKSETT DAM

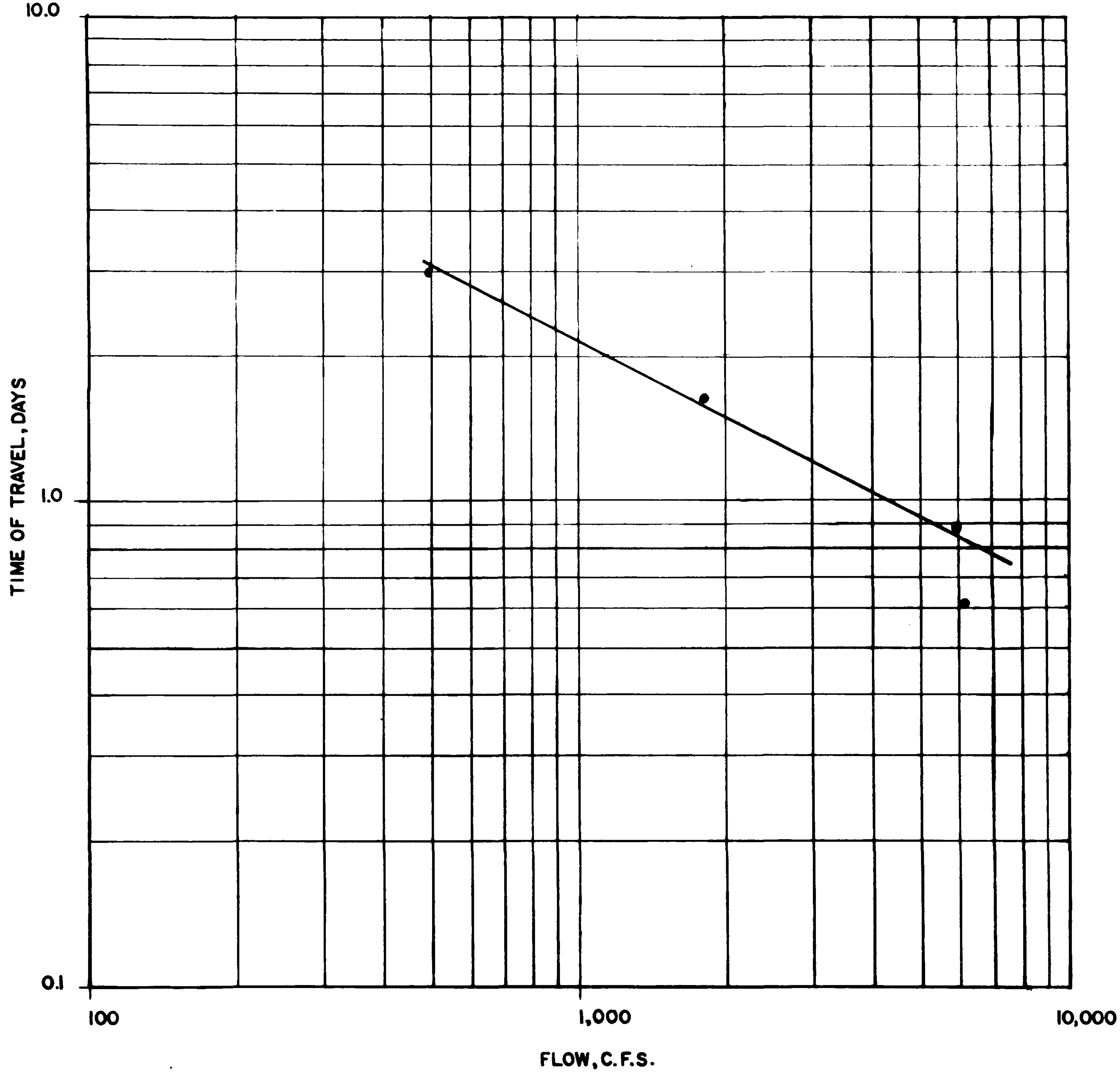
FIGURE 4



MERRIMACK RIVER

TIME OF TRAVEL VS. FLOW - HOOKSETT DAM TO AMOSKEAG DAM

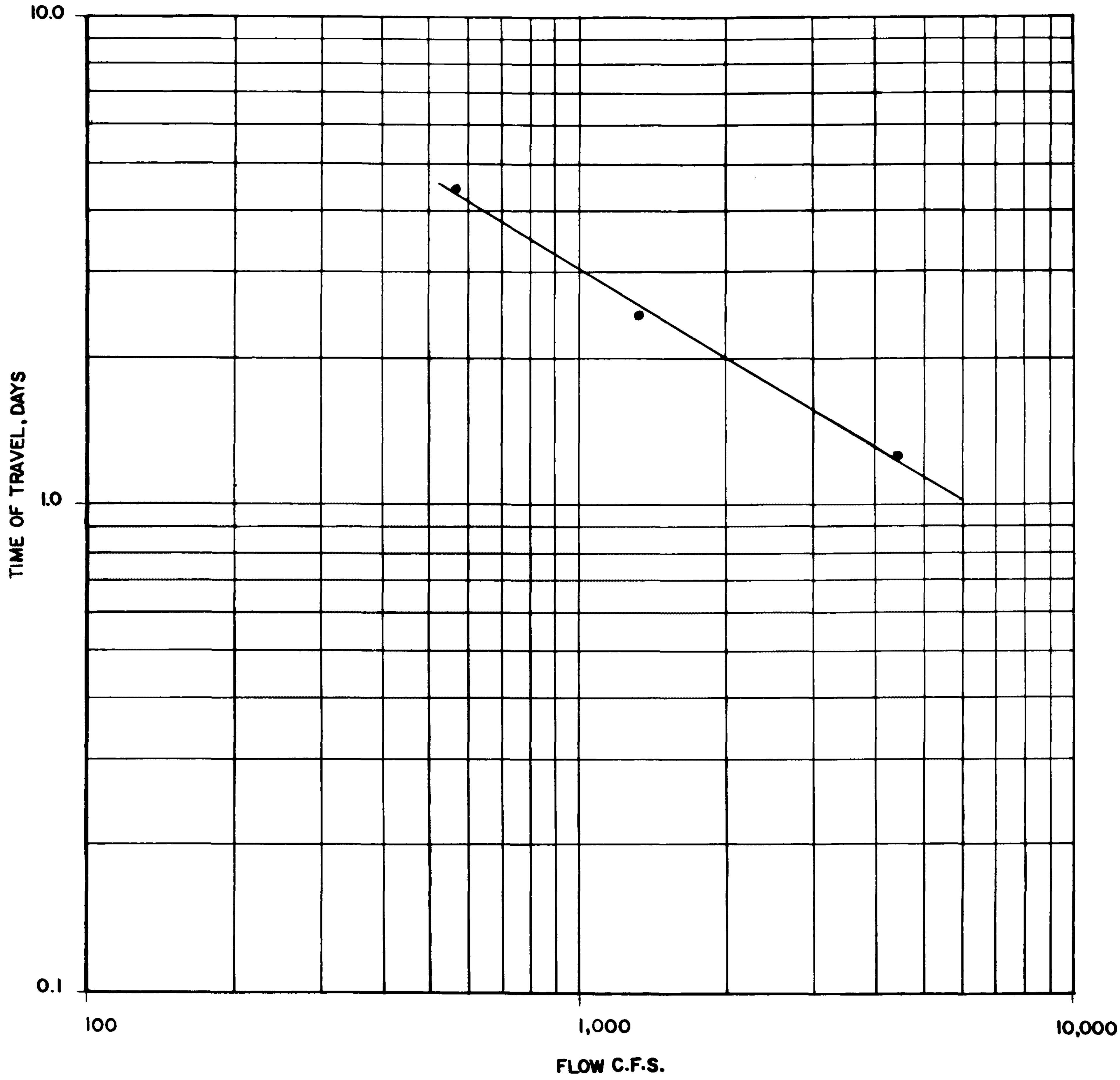
FIGURE 5



MERRIMACK RIVER

TIME OF TRAVEL VS. FLOW - AMOSKEAG DAM TO NASHUA RIVER

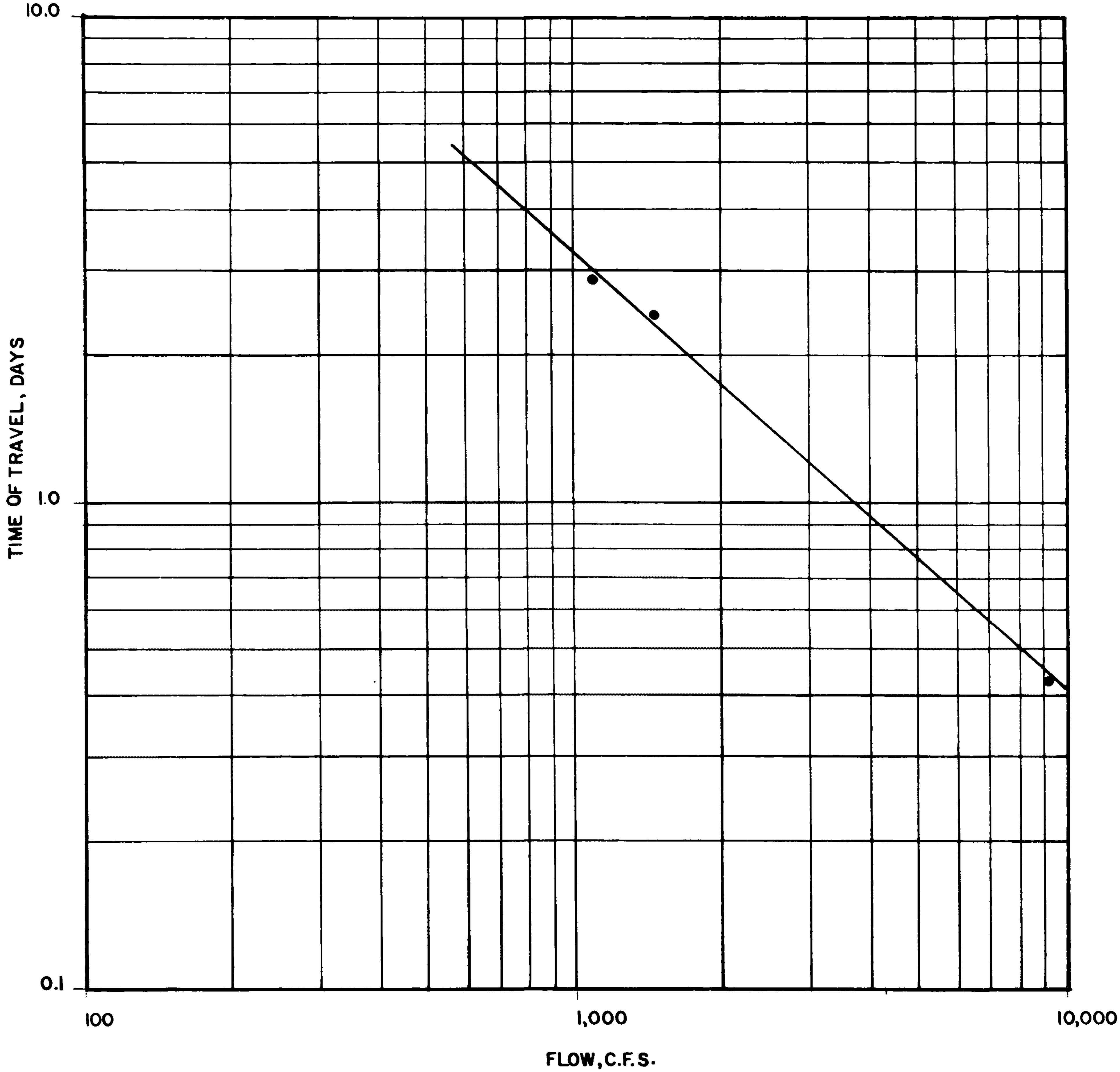
FIGURE 6



MERRIMACK RIVER

TIME OF TRAVEL VS. FLOW - NASHUA RIVER TO CONCORD RIVER

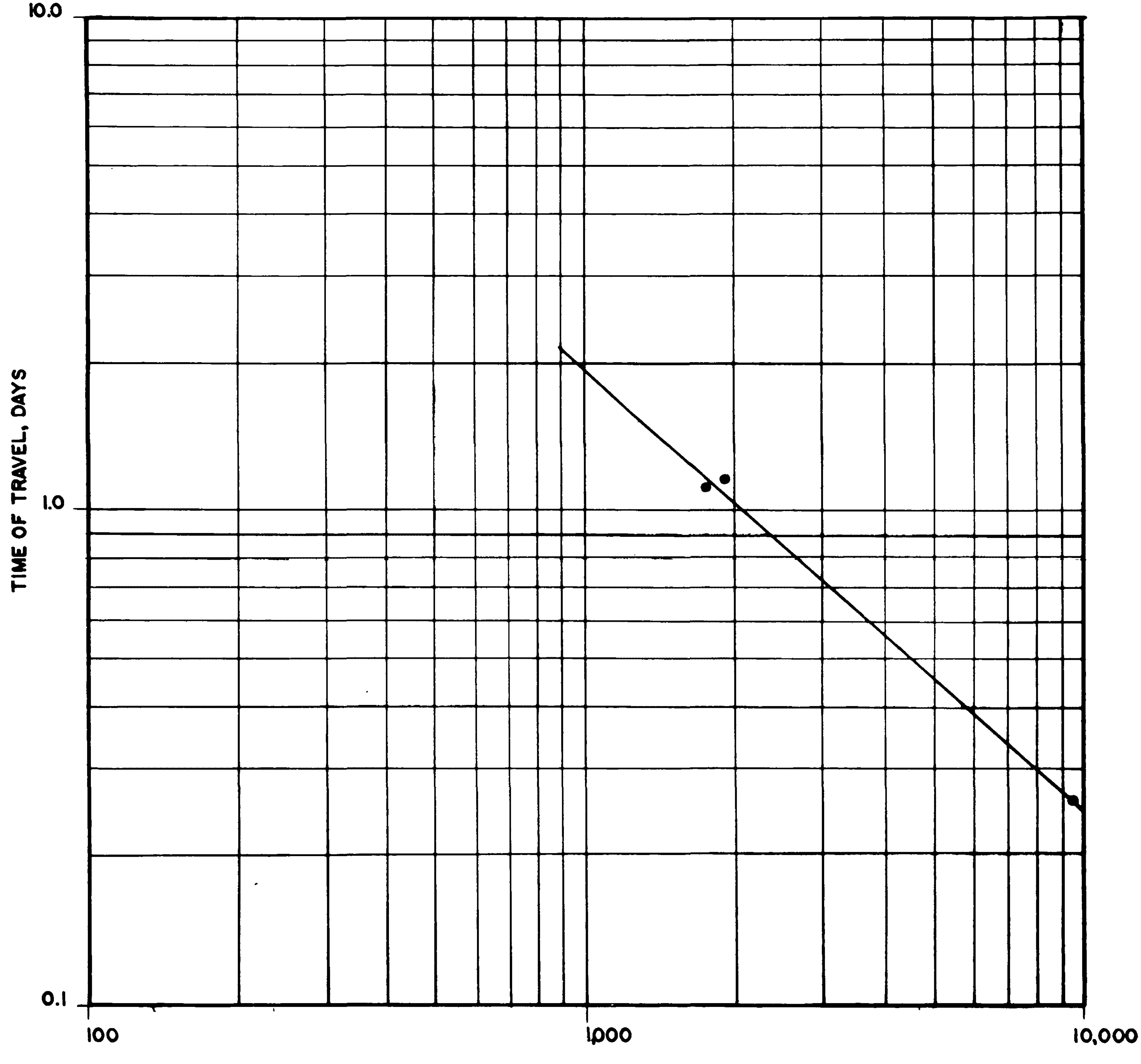
FIGURE 7



MERRIMACK RIVER

TIME OF TRAVEL VS. FLOW - CONCORD RIVER TO LAWRENCE

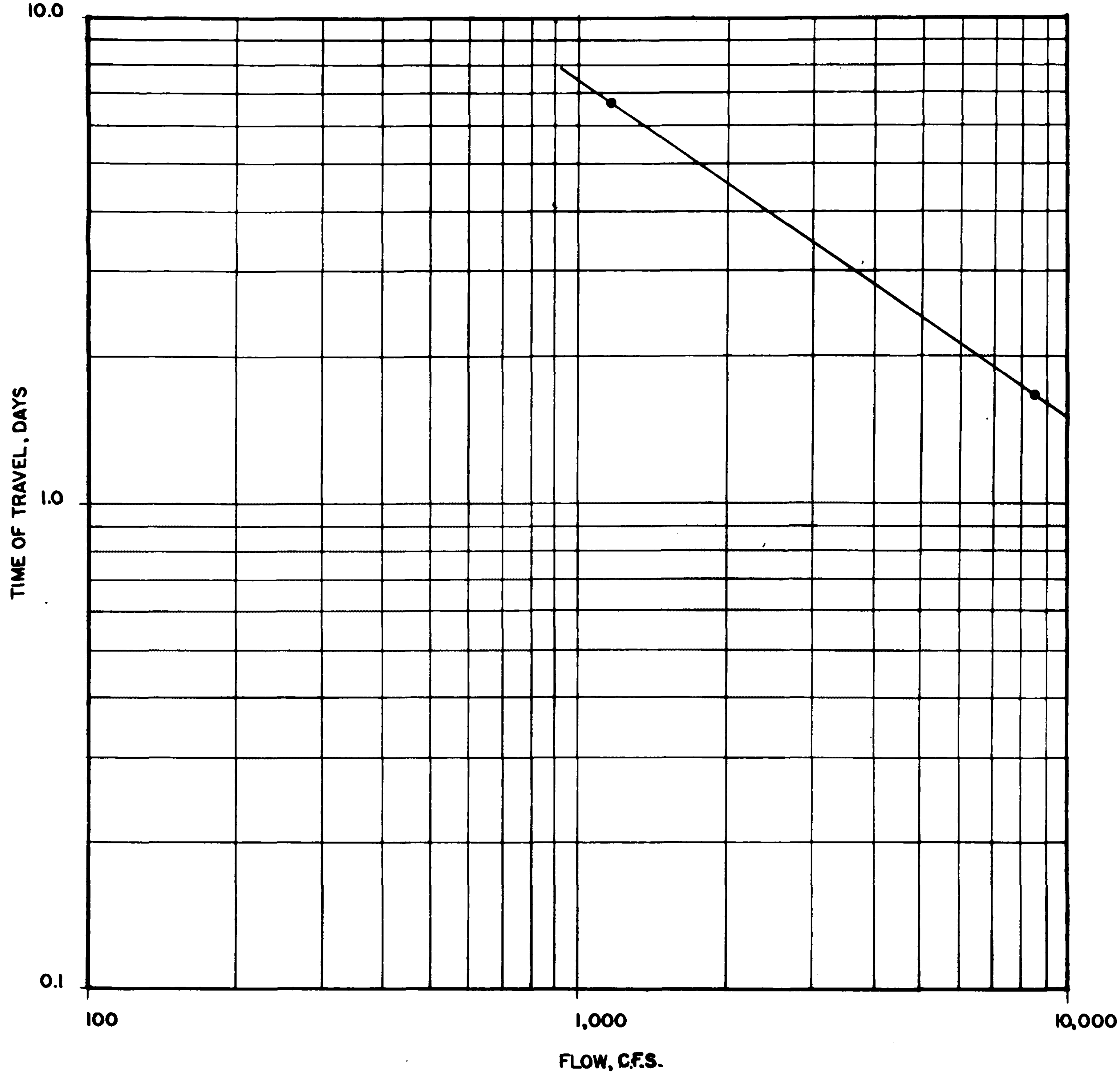
FIGURE 8



MERRIMACK RIVER

TIME OF TRAVEL VS. FLOW - LAWRENCE TO LITTLE RIVER

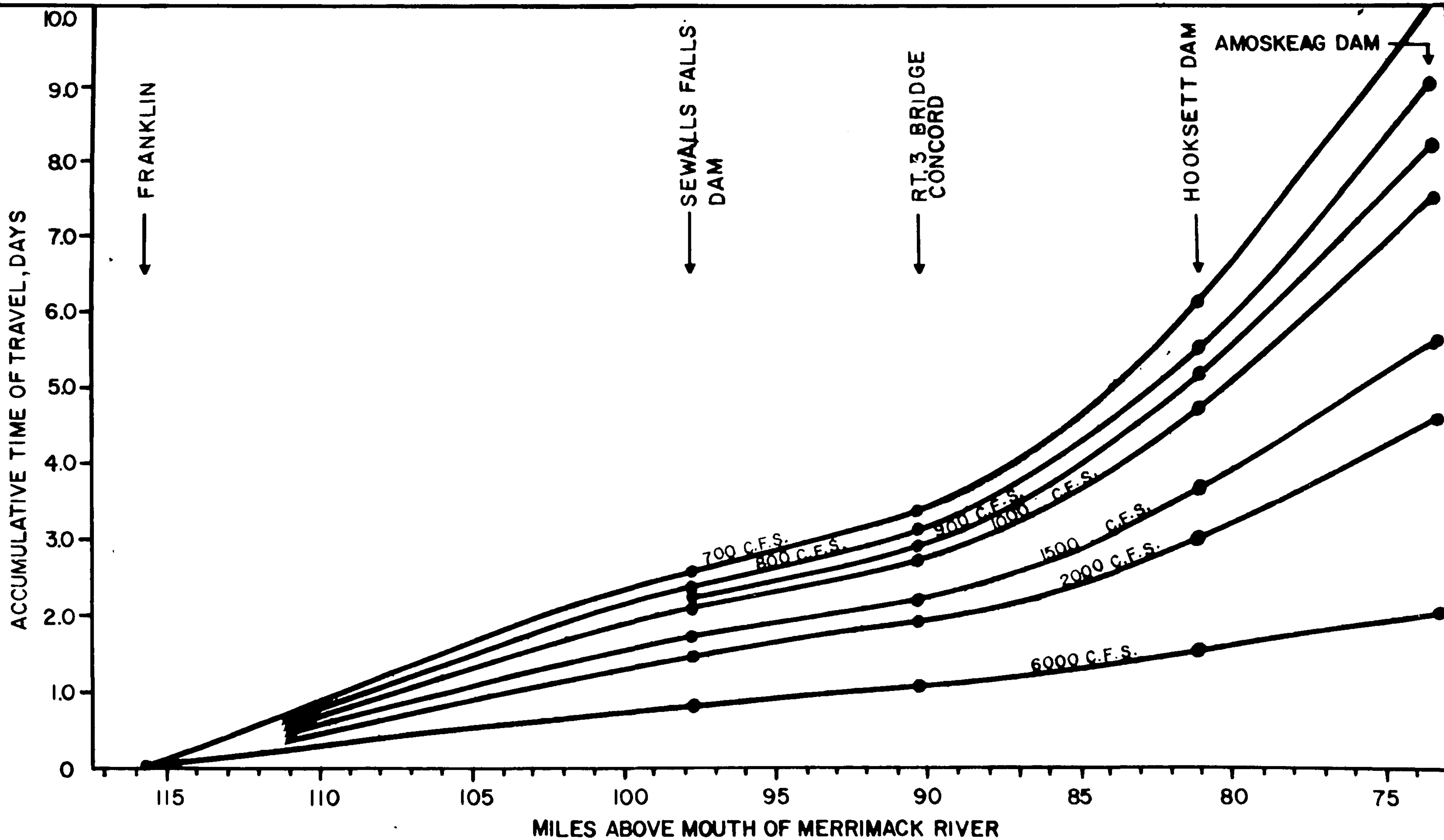
FIGURE 9



MERRIMACK RIVER

TIME OF TRAVEL VS. FLOW - LITTLE RIVER TO NEWBURYPORT

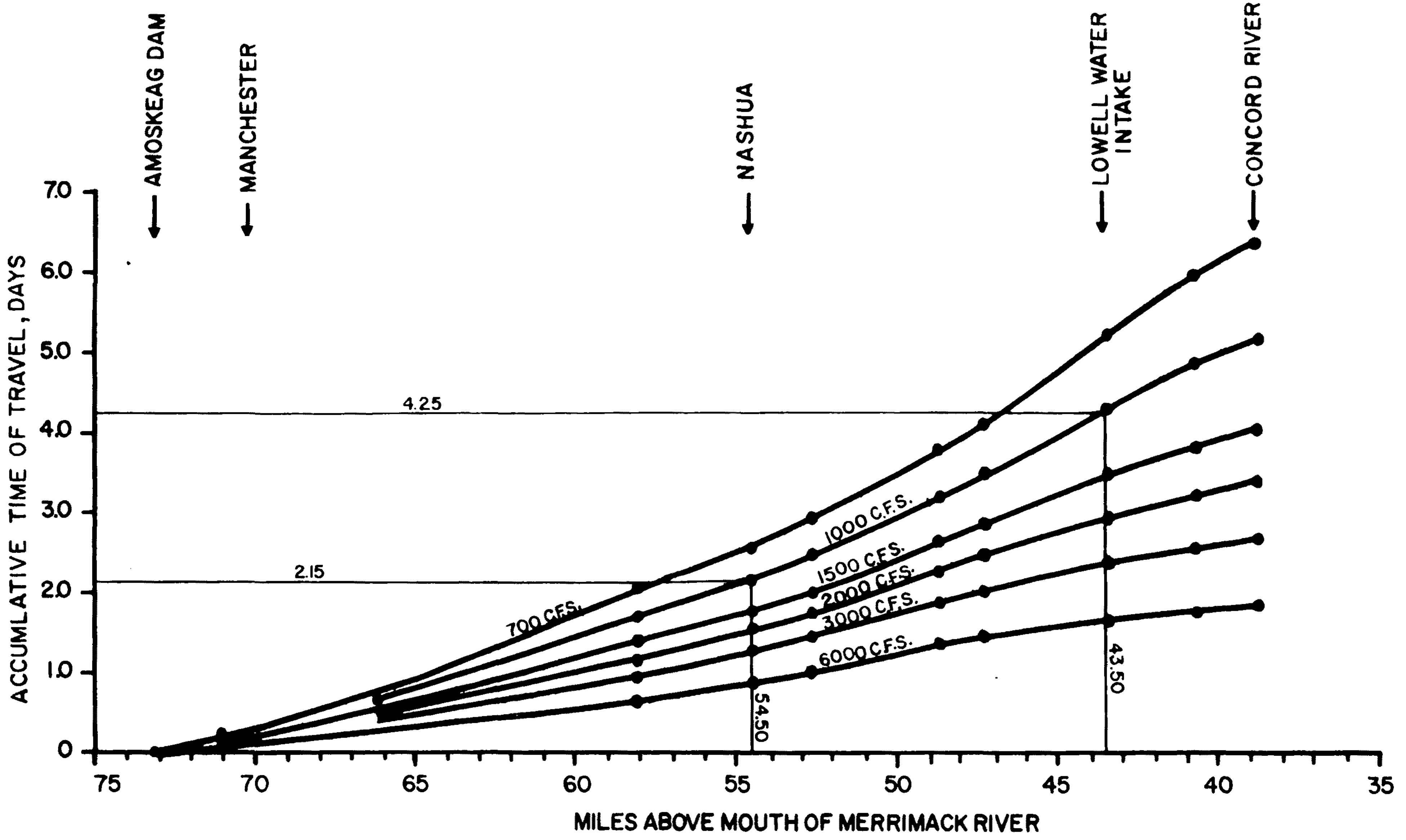
FIGURE 10



TIME OF TRAVEL

MERRIMACK RIVER MILES 116 TO 73

FIGURE 11



TIME OF TRAVEL
MERRIMACK RIVER MILES 73 TO 39

FIGURE 12

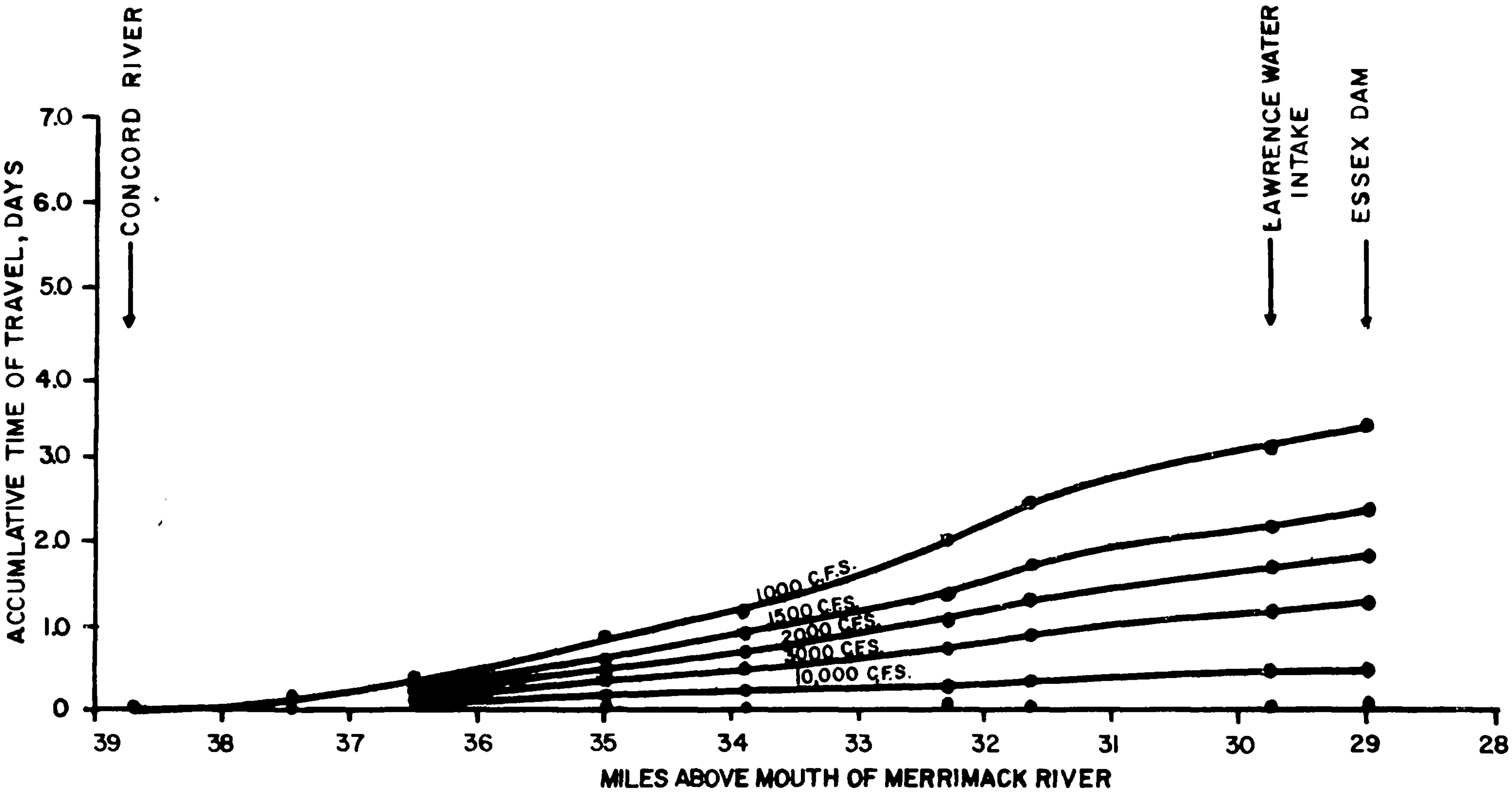
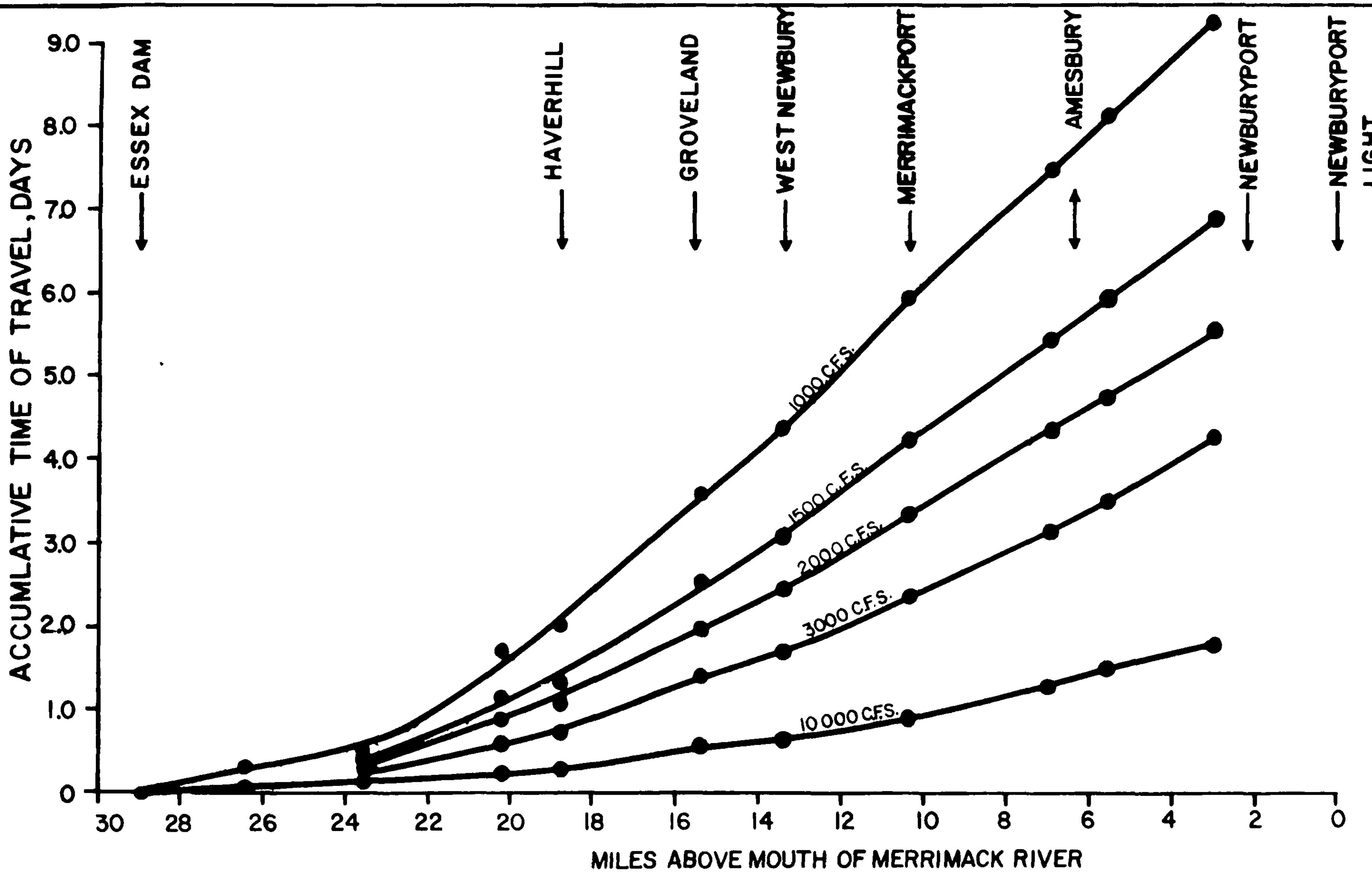


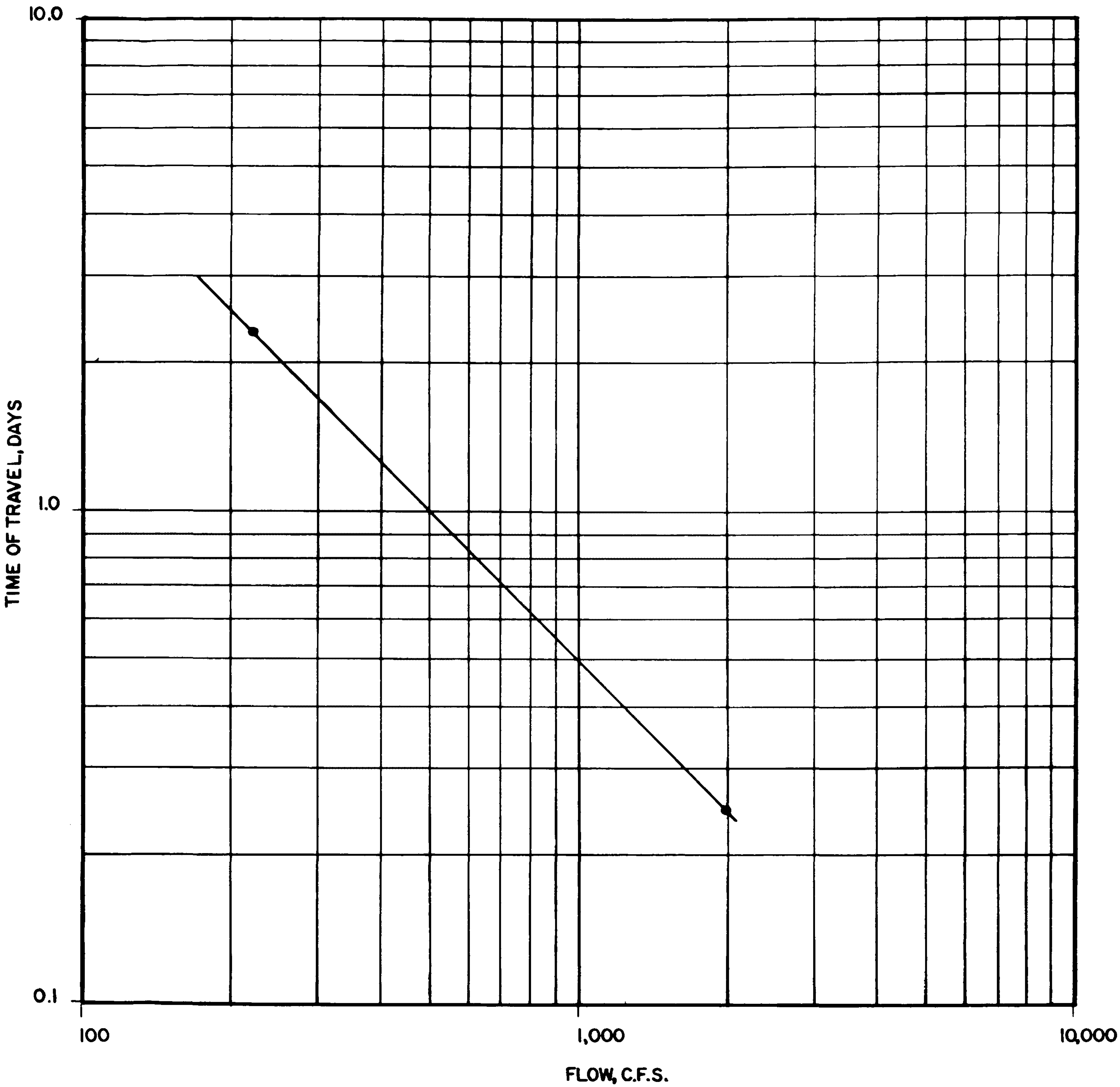
FIGURE 13

TIME OF TRAVEL
MERRIMACK RIVER MILES 39 TO 29



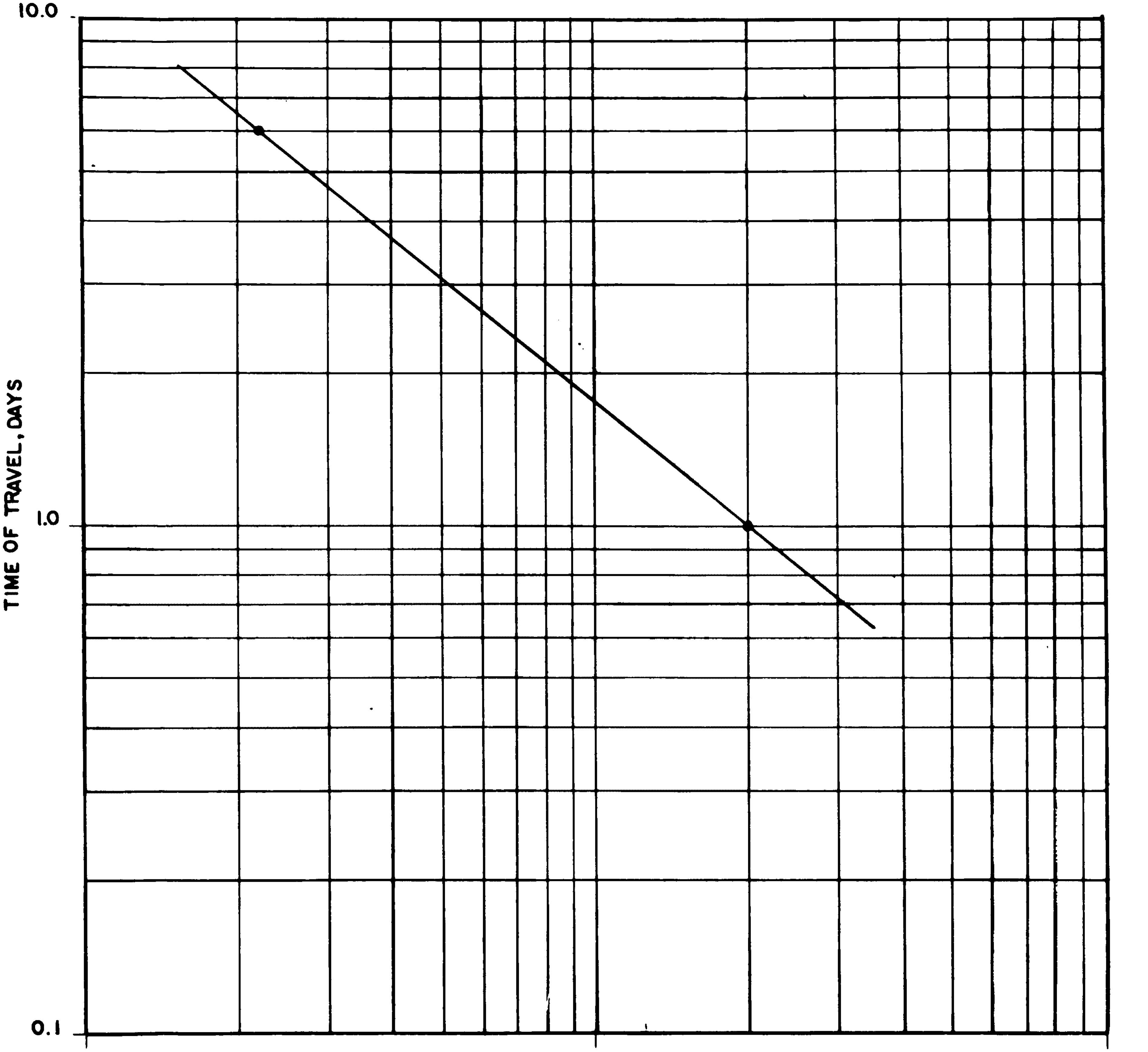
TIME OF TRAVEL
MERRIMACK RIVER MILES 29 TO 3

FIGURE 14



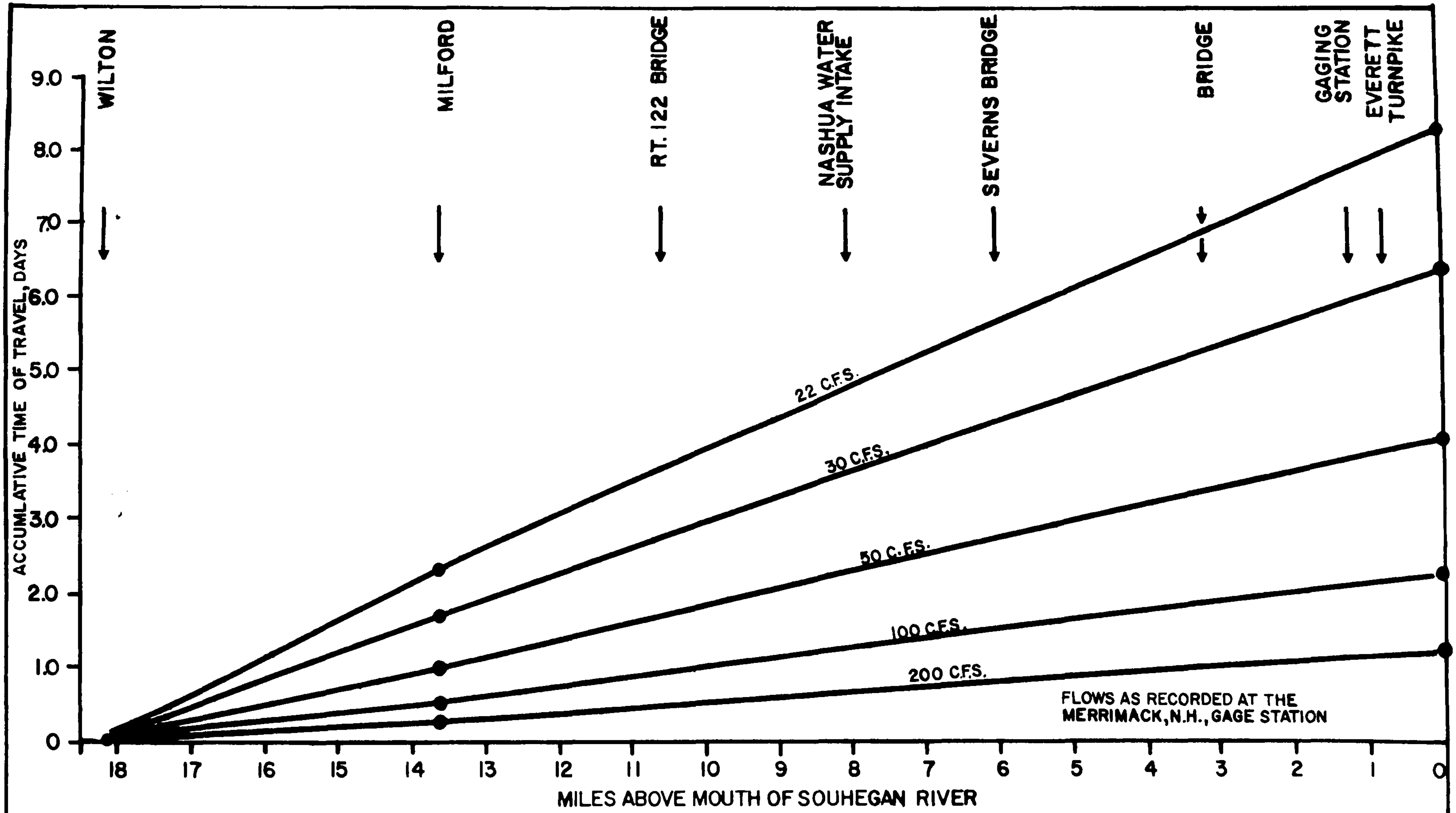
SOUHEGAN RIVER - TIME OF TRAVEL VS. FLOW - WILTON TO MILFORD

FIGURE 15



SOUHEGAN RIVER - TIME OF TRAVEL VS. FLOW - MILFORD TO MOUTH

FIGURE 16



TIME OF TRAVEL OF SOUHEGAN RIVER

FIGURE 17

EFFECTS OF POLLUTION ON STREAM QUALITY

For the purposes of this study, the evaluation of stream quality was based primarily on a "sanitary water analysis", i.e. temperature, dissolved oxygen, biochemical oxygen demand, and coliform bacteria. A limited nutrient (phosphorus and nitrogen) sampling program and a very limited industrial waste program was conducted.

Three of the factors of stream pollution—temperature, dissolved oxygen (DO) and biochemical oxygen demand (BOD)—are all interrelated. As organic matter having a BOD is added to the river by sewage and industrial discharges, bacteria begin to act upon the organic matter and convert it to cell material and carbon dioxide. By this natural process the organic matter is removed from the stream. During this decomposition of waste material, the dissolved oxygen of the river is utilized. If the BOD is sufficiently high, the DO may be lowered to the point that it cannot support fish and other aquatic life. Most water pollution control agencies have adopted a value of 5.0 ppm of dissolved oxygen as the minimum level necessary to maintain the maximum potential warm water sport fish population. When the DO is at or near zero, anaerobic decomposition may occur. Such decomposition often results in gasification, producing carbon dioxide, methane and hydrogen sulfide. The most noticeable results are "rotten egg" odors, black water and discoloration of paint on nearby structures.

In the relationship of BOD stabilization and DO concentration, temperature plays an important role. An increase in temperature has two effects: (1) the organic material is stabilized at a faster rate and, therefore, the dissolved oxygen is utilized at a higher rate; and (2) the saturation value for dissolved oxygen is reduced, thereby decreasing the amount of oxygen that a stream can dissolve.

Nitrogen and phosphorus are two nutrients important to aquatic plant growth. Although several other nutrients are essential for growth, they are generally required in minute amounts. Concentrations of nitrogen and phosphorus are often used to indicate potential algal growths.

For each variable, water quality data obtained during 1964-65 are discussed below. A list of sample station codes, river miles and descriptions are given in Appendix A. Temperature, DO and BOD data are summarized in Appendix B and coliform data in Appendix C.

TEMPERATURE

Temperature values ranged from a low of -1°C at several stations during January, February and March of 1965 to a high value of 30° below the Public Service Company of New Hampshire power plant at Bow, New Hampshire. Excluding the estuary, very little temperature variations were noted during consecutive sampling days at any one station. In general, there was no significant variation between sample stations in a particular reach. Minimum, maximum and average values are reported in Appendix B for significant sampling periods. During the concentrated summer sampling period of 1964, the temperature average for the 19 non-estuary samples was 21.9°C. For the summer of 1965, the 30 stations sampled averaged 23.9°C. This difference can be attributed mainly to a lower flow at the time of sampling in 1965. For the combined values of the two years the temperature averaged 23°C.

There was only one major source of thermal pollution noticed in the study, that being the Public Service Company of New Hampshire power plant at Bow, New Hampshire. This effluent raised the temperature an average of 3°C just below the outfall. Any expansion of this plant or construction of new facilities in the Merrimack River Basin should provide for the cooling of the waste discharges.

There were no significant temperature differences observed between the Merrimack River and its major tributaries.

DISSOLVED OXYGEN

Maximum, average and minimum dissolved oxygen values of the Merrimack River obtained during significant sampling periods are summarized in Appendix B. The maximum value occurring in the Merrimack River was 12.9 ppm (92 per cent of saturation) and was recorded during the period of high river flow in April, 1965. During the low flow summer months, the maximum value was 9.7 ppm. In August of 1964, the river was devoid of dissolved oxygen at stations HN-1.0 and HN-2.0 below Haverhill, Massachusetts.

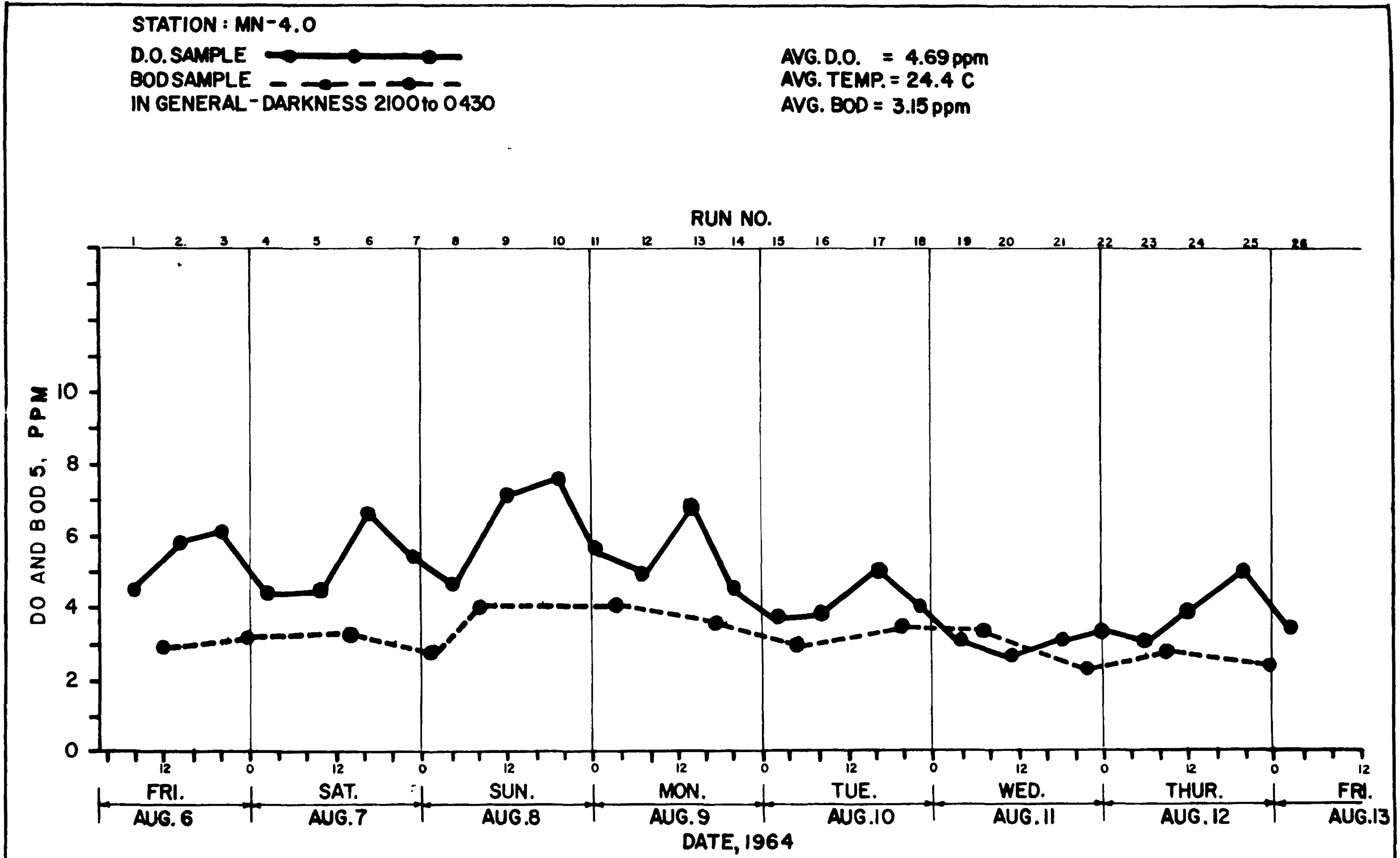
Most of the stations displayed a daily fluctuation in DO values. The primary cause of this cyclic fluctuation was the use of oxygen by aquatic plants at night and the production of oxygen by photosynthesis during the day. A typical dissolved oxygen pattern is shown in Figure 18. Photosynthesis can be retarded during the daytime if the amount of solar radiation reaching the algae is significantly reduced by cloud cover. This effect is apparent on Wednesday, August 11, in the figure. Daily variations in the cycle can be attributed to variations in solar radiation plus variations in river flow and waste load.

The ice cover on the Merrimack River during the winter season did not result in low dissolved oxygen concentrations. Apparently the turbulence of the water as the river was diverted through the canals and factories and the occasional open stretches of water enabled sufficient reaeration to occur to prevent low dissolved oxygen values.

Dissolved oxygen results in the Merrimack River during June, July, August and September of 1964 and 1965 are summarized in Figure 19. Only 17 of the 43 sample points had an average value in excess of 5.0 ppm of dissolved oxygen. None of the minimum values was greater than 5.0 ppm.

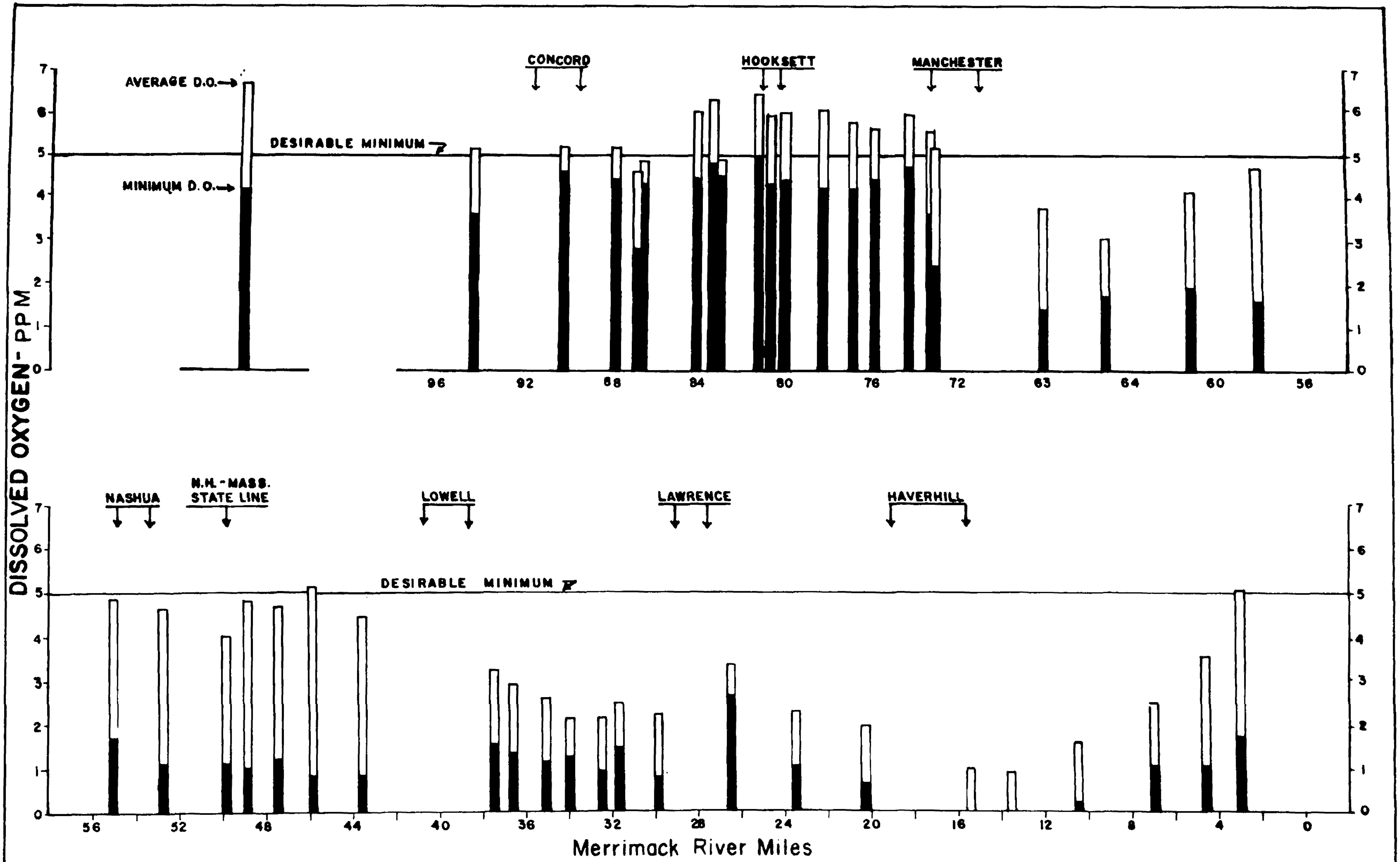
Between Concord and Manchester, New Hampshire, the dissolved oxygen was moderately depressed by the waste loads from the communities and industries of Concord, Pembroke, Allenstown and Hooksett, New Hampshire. In this section the minimum values varied between 3.9 and 5.0 ppm. Average values were near or above 5.0 ppm.

After receiving the domestic and industrial wastes of Manchester, New Hampshire, the river became grossly polluted. Additional waste loads



TYPICAL DISSOLVED OXYGEN & BOD PATTERNS IN THE MERRIMACK RIVER

FIGURE 18



DISSOLVED OXYGEN IN MERRIMACK RIVER

JUNE, JULY, AUGUST & SEPTEMBER 1964-1965

FIGURE 19

of Nashua and Hudson, New Hampshire, and the greater Lowell, Lawrence, and Haverhill regions succeeded in preventing the river from ever recovering in this reach. Averages in this seventy-two mile section varied from a high of 5.11 ppm of dissolved oxygen to a low of 0.88 ppm. Minimum values were less than 2.0 ppm at all stations except one, and zero dissolved oxygen values were found at two points.

A depletion in the oxygen supply of a river will reduce or eliminate aquatic life which serves as food for fish. The biological stream studies conducted on the Merrimack River[8] showed that these benthic organisms, sensitive in their responses to pollution, were totally absent in the lower fifty-seven miles of the Merrimack River. In only four very short reaches of the entire Merrimack River, less than 15 miles out of a total of 115, did the river recover enough from its despoiled condition to permit a small number of sensitive organisms to exist.

BIOCHEMICAL OXYGEN DEMAND

The biochemical oxygen demand (BOD) of the Merrimack River is summarized in Appendix B. Very little variation was observed between the maximum and minimum values at a given station, as shown in Figure 18. The maximum value present in the Merrimack River was 11.2 ppm below Lawrence, Massachusetts; the minimum value was 0.7 ppm, occurring above Hooksett, New Hampshire. The most polluted reach of the Merrimack River, as indicated by BOD analysis, was between Lawrence and Haverhill. In this reach, the average BOD was 6.73, 7.63 and 8.54 ppm at the three stations.

"Long-term" BOD analyses were conducted at several stations. These data, found in Appendix B, were used to determine the rate of BOD stabilization and the degree of second stage BOD. From Manchester, New Hampshire, to below Haverhill, Massachusetts, the second stage BOD was found to be significant.

In August of 1964 there were 28,800 pounds of BOD per day crossing the state line from New Hampshire into Massachusetts, exclusive of the 2,600 pounds per day added by Massachusetts by way of the Nashua River. This is equivalent to the discharge of raw sewage from a city of 169,000 people. When the BOD remaining from New Hampshire reaches Lowell, Massachusetts, it equals the total domestic and industrial wastes discharged by the Lowell regional communities to the river.

In 1965 the contribution of each New Hampshire community and the Nashua River to the BOD crossing the state line is shown below:

Manchester	52 per cent
Nashua-Hudson	23 per cent
Nashua River	17 per cent
Concord	4 per cent
Other	4 per cent

The Nashua River portion at the state line is actually contributed by Massachusetts and represents the residual wastes of that discharged to the Nashua River before the river crosses into New Hampshire.

BACTERIA

In the early part of this century typhoid fever epidemics were commonplace in many cities which used surface streams as sources of supply and provided little or no water treatment. These epidemics have been brought under control, largely by modern treatment methods. The fear of pathogenic bacteria in the water has decreased to the point that one city official commented recently that there was no public health significance to the discharging of raw sewage to the Merrimack River. In determining the bacterial pollution of a river, the pathogenic organisms are usually not isolated and identified because of the time involved in carrying the test to completion. Very few samples could be analyzed if these tests were used to determine bacterial pollution of a river.

In order to get a more comprehensive view of the bacterial pollution, indicator organisms are used. Coliform bacteria are indicators most commonly used in stream studies because they are common to the intestinal tract of man and of other warm blooded animals and can be identified with relative ease. Two types of coliform tests are commonly used—fecal coliform and total coliform. The fecal coliform test is a measure of fecal coliforms from warm-blooded animals, including man, whereas the total coliform test may include fecal coliforms as well as certain other bacteria, such as organisms from the soil. It should be noted, however, that in addition to being indicator organisms, certain serotypes of Escherichia coli, a fecal coliform, could also be pathogenic[9]. Hinton and MacGregor reported[10], "there seems little doubt that infections due to pathogenic serogroups of E. coli constitute an important fraction of these cases of gastro-enteritis in childhood whose etiology can be specifically defined. The threat of epedemic enteritis, in highly susceptible populations, may well be significantly decreased by the appreciation of the importance and epidemiology of E. coli infections."

Geldreich, et. al.[11] determined the coliform bacteria in human feces, using the completed most probable number (MPN) test and reported an average of 1.95 billion/capita/day. Raw sewage from large cities commonly has a confirmed MPN of 15 to 30 million per 100 ml in the summer and 5 to 10 million per 100 ml in winter[12]. On this basis and assuming 100 gallons/capita/day of wastewater flow, there are 57 to 114 billion coliform bacteria per capita in raw sewage in summer and 19 to 38 billion/capita/day in winter.

Two methods are used to quantitatively measure coliform bacteria. The multiple-tube decimal dilution (MPN) method, mentioned above, was used during the 1964 studies of the Merrimack River and occasionally during 1965. The membrane filter (MF) method was used during the majority of the 1965 samplings. The method used is recorded with the results in Appendix C. When results of the MPN and MF tests on Merrimack River water were compared, it was found that the MF gave values that were on the average 48 per cent of the total coliform MPN and 57 per cent of the fecal coliform MPN.

The continuing increase in water recreation and the parallel increase in the volume of wastes discharged from our cities is resulting in the direct exposure of increasingly large numbers of persons to the hazards of ingesting pathogenic organisms. The 40 million or more water sportsmen in the United States have no protective barrier comparable to the water treatment plant between themselves and the pathogenic organisms in the water in which they swim, ski, fish, boat and hunt. Few of them know that the water is contaminated or realize the hazards of accidental or intentional ingestion of surface waters. Many still believe in the ancient adage that a river purifies itself every seven miles, although Salmonella bacteria have been found as far as 75 miles downstream from the nearest outfall[13].

In addition to the increase in coliform bacteria in raw sewage due to their multiplication, there may be a similar increase in the receiving stream. A maximum coliform density may occur about one half day below the point of discharge as a result of this "aftergrowth". This increase occurred in the Lowell to Lawrence reach of the Merrimack River.

To determine coliform densities in the Merrimack River several intensive studies were undertaken during the summer months of 1964 and 1965. These intensive studies were supplemented by shorter sampling periods during the other seasons of the year. Data for both years are summarized in Appendix C.

As shown in Figure 20, raw sewage discharged at Concord, Manchester and Nashua, New Hampshire, resulted in a large increase in coliform bacteria. The Merrimack River had an average coliform density (MF) of 249,000 per 100 ml and an average fecal coliform density of 18,600 per 100 ml below Manchester during the summer months.

As shown in Figure 21, during the summer the discharges at Nashua, New Hampshire, and Lowell, Lawrence and Haverhill, Massachusettes, produced excessive coliform densities. Just below the state line the total and fecal coliform values were 67,000 and 14,600 MPN per 100 ml, respectively. At the Lowell water intake the total coliform density averaged 15,100 MPN per 100 ml and the fecal coliform density averaged 2,500 MPN per 100 ml.

The river had the highest coliform density in the Lawrence to Haverhill reach. The average total coliform density was 1,910,000 MPN per 100 ml and the average fecal coliform density was 213,000 MPN per 100 ml below Lawrence. At this station a maximum value of 9,200,000 MPN per 100 ml was obtained for the total coliform density and a maximum of 542,000 MPN per 100 ml for the fecal coliform density.

Several limited studies were conducted during the fall of 1964 and 1965. The results of the studies are summarized in Appendix C. Figure 20 shows the river condition in 1965. Colder river water, being more favorable to the survival of bacteria, is the main reason for the densities being greater than those of the summer period. At the Lowell water intake, the total coliforms were 27,900 per 100 ml and the fecal coliforms averaged 6,900 per 100 ml. Bacteria reaching Massachusetts from New Hampshire discharges during this period were considerably higher than the desirable minimum densities of coliform bacteria. The months of September, October and November were the periods of the highest coliform densities in the Merrimack River.

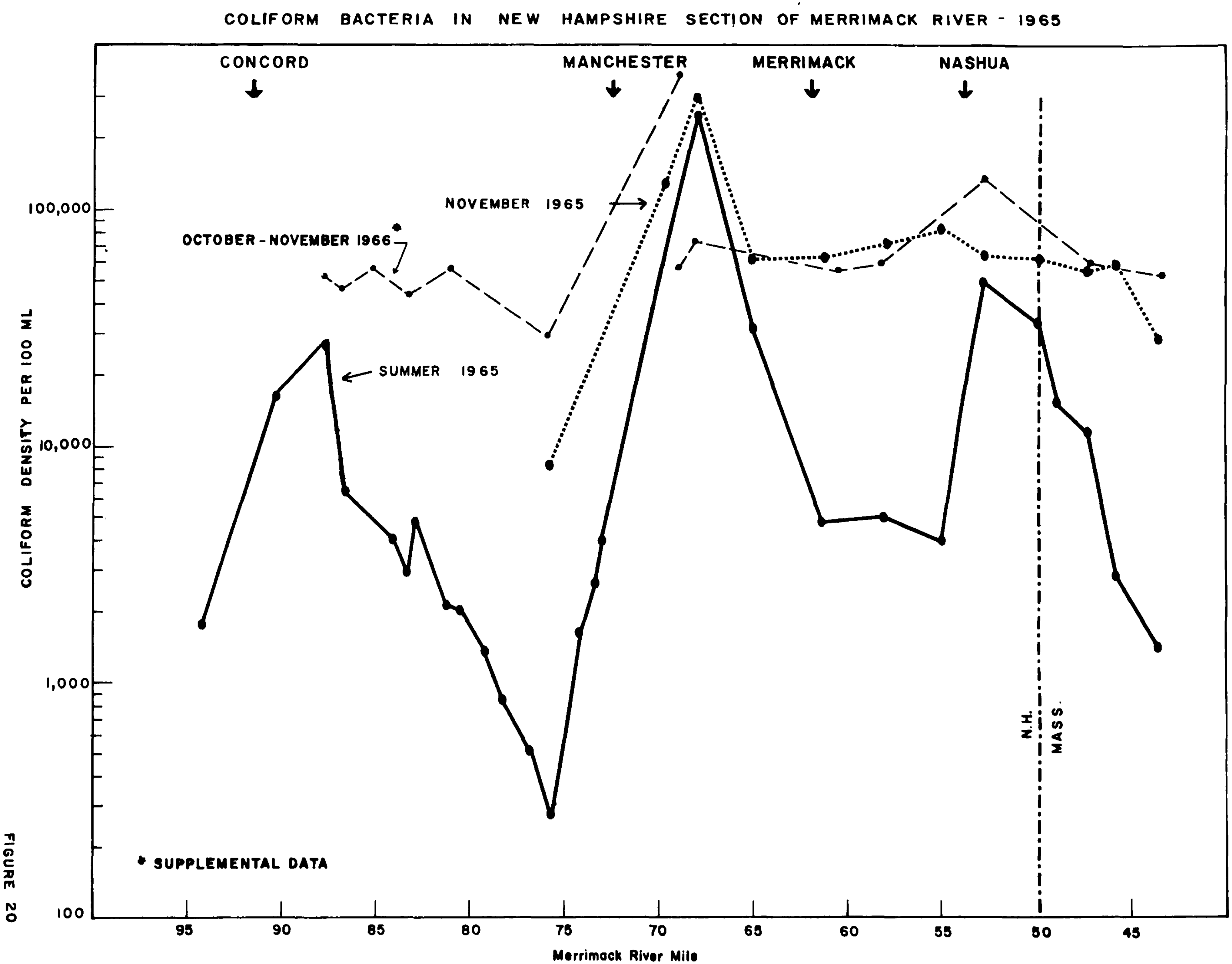
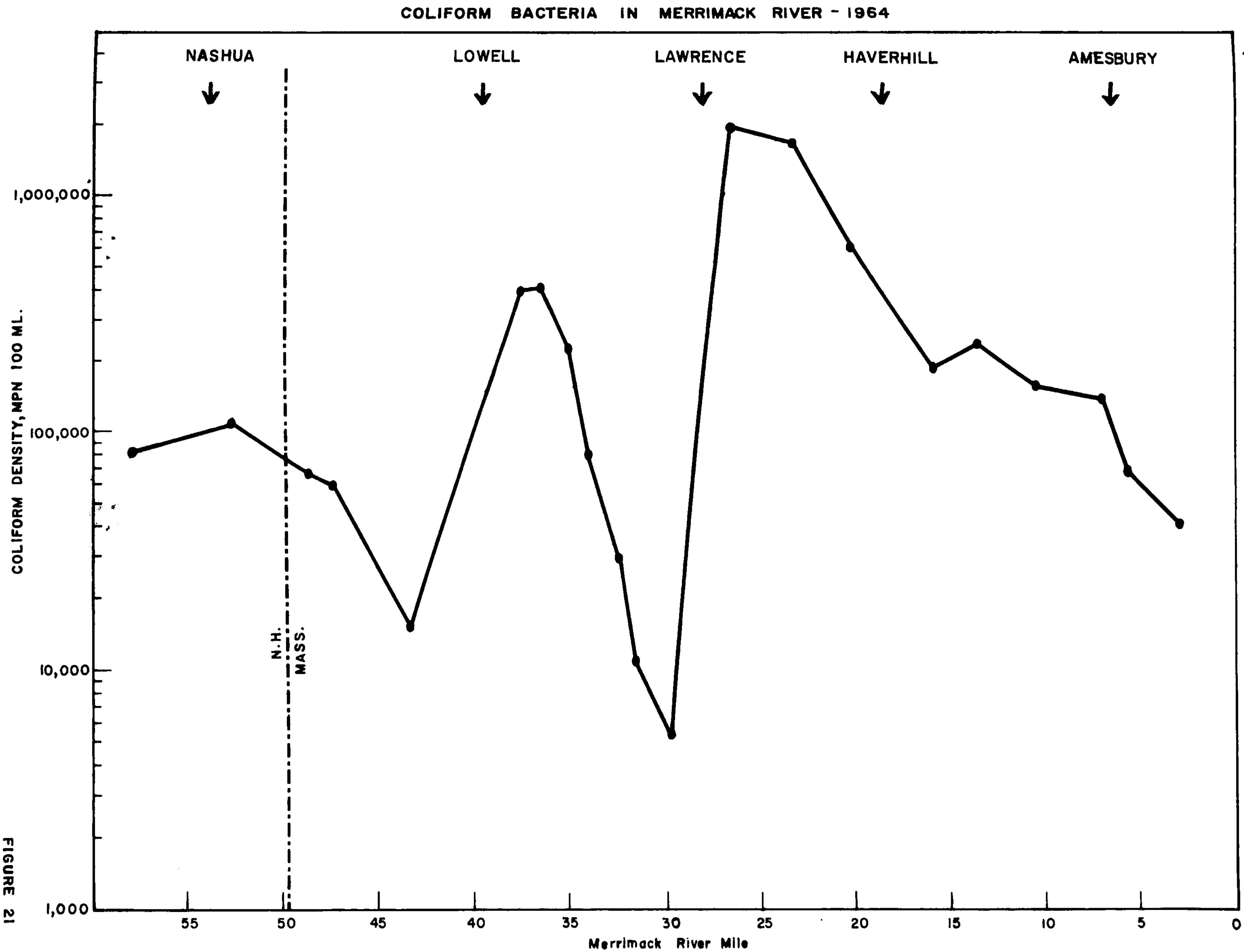

COLIFORM BACTERIA IN NEW HAMPSHIRE SECTION OF MERRIMACK RIVER - 1965
CONCORD
MANCHESTER
MERRIMACK
NASHUA
NOVEMBER 1965
OCTOBER-NOVEMBER 1966
SUMMER 1965
N.H.
MASS.
SUPPLEMENTAL DATA
COLIFORM DENSITY PER 100 ML
100,000
10,000
1,000
100
95
90
85
80
75
70
65
60
55
50
45
Merrimack River Mile

FIGURE 20



COLIFORM BACTERIA IN MERRIMACK RIVER - 1964
NASHUA
LOWELL
LAWRENCE
HAVERHILL
AMESBURY
N.H.
MASS.
COLIFORM DENSITY, MPN 100 ML.
1,000,000
100,000
10,000
1,000
55
50
45
40
35
30
25
20
15
10
5
0
Merrimack River Mile

FIGURE 21

Very short studies were conducted during the winter and spring months of the year. Data obtained indicated that the coliform densities in the Merrimack River during these periods were generally greater than those during the summer months but not as high as during the fall of the year.[1]

BACTERIAL DECLINE

As indicated previously, the coliform density is used as a bacterial index of safety for waters, on the assumption that the number of infectious organisms decline in proportion to the reduction in the count of coliform bacteria. In a natural body of water, an initial rise in bacterial count (after growth) followed by a decline (die-off) is often found. Rates of bacterial decline can be obtained from the initial decline phase after the peak count has been reached by plotting coliform densities against time of flow. The three major causes of this decline are predators, settling and an unfavorable environment.

Figures 22 through 29 were prepared to show the bacterial decline in the Merrimack River. The per cent of coliform density remaining after various daily intervals for the concentrated summer sampling periods is summarized in Table 5 for the total coliform data and Table 6 for the fecal coliform data. Considerable variation was found in the various reaches of the Merrimack River. Hoskins[14] reported that there

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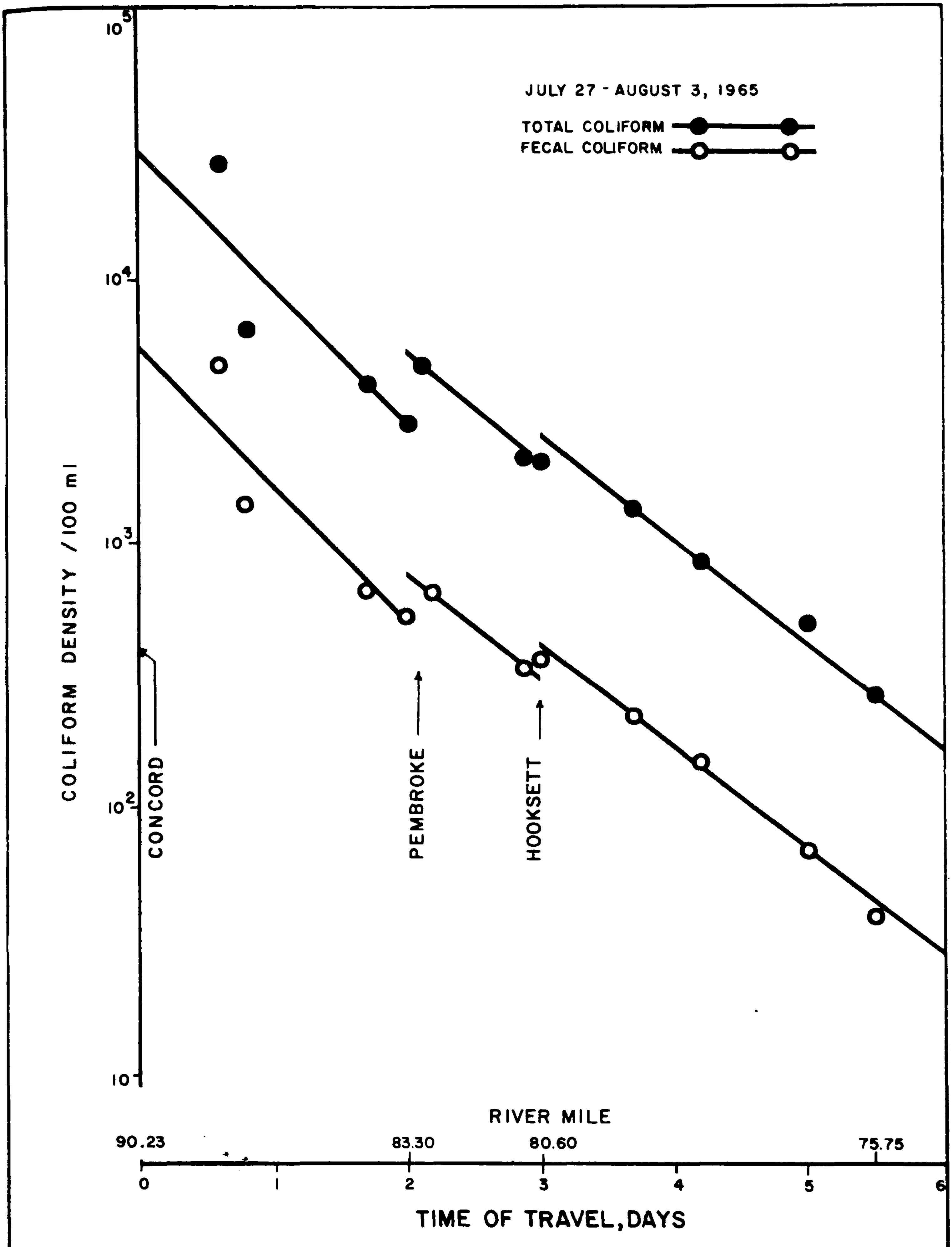
[1]Supplemental data were obtained in October and November, 1966, from Concord, New Hampshire, to Lowell, Massachusetts. These data are shown in Figure 20. Coliform densities far in excess of those found during the summer were obtained.

TABLE 5

TOTAL COLIFORM DENSITY DECLINE

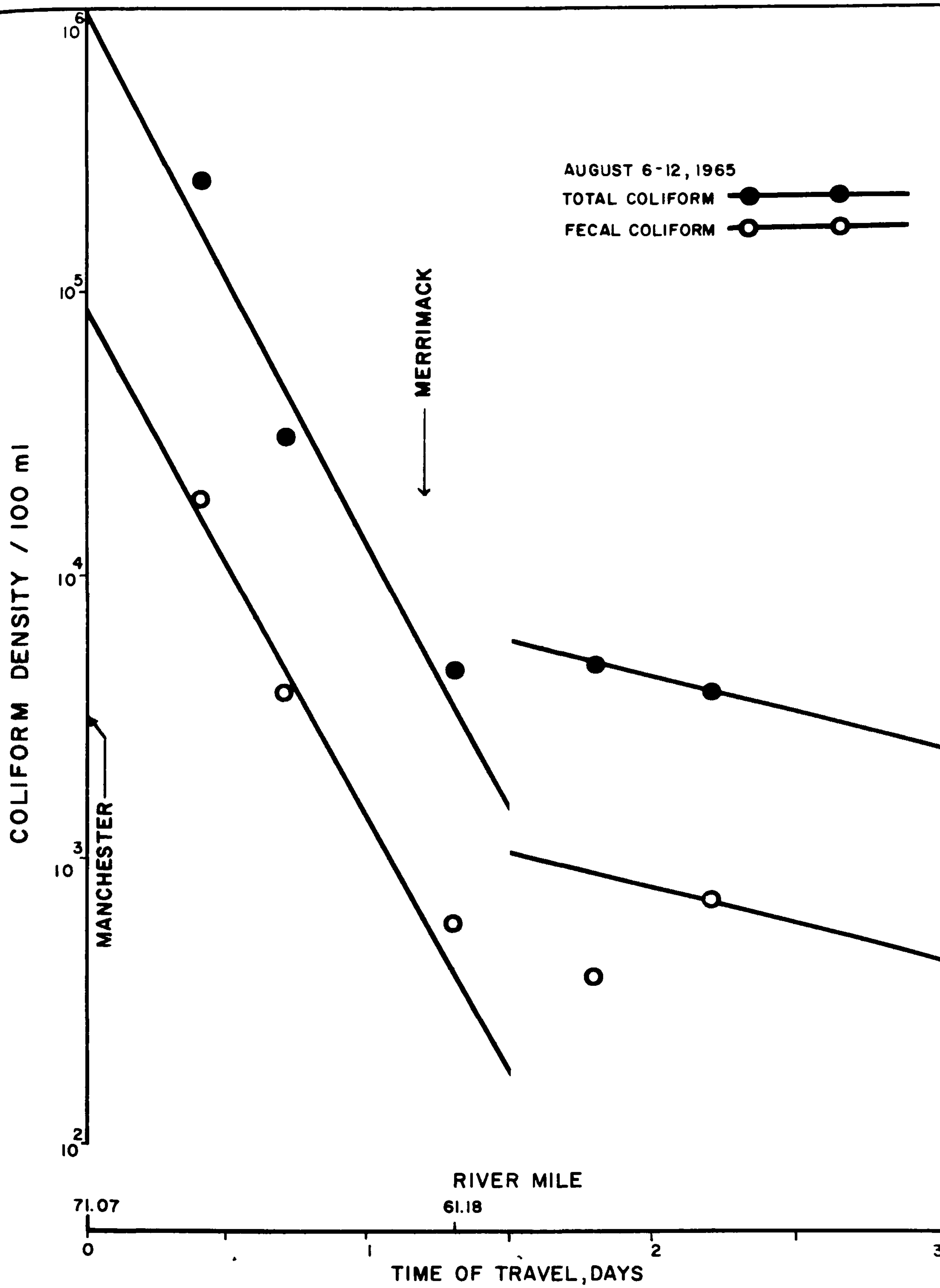
Summer

MERRIMACK RIVER	DATE	TOTAL COLIFORM DENSITY % Remaining After Daily Intervals		
		1 Day	2 Days	3 Days
Concord to Pembroke	Aug 65	31.0	9.8	---
Pembroke to Hooksett	Aug 65	37.7	---	---
Hooksett to Manchester	Aug 65	40.0	16.1	6.5
Manchester to Merrimack	Aug 65	1.5	---	---
Merrimack to Nashua	Aug 65	55.0	---	---
Nashua to Lowell	Aug 65	11.0	1.2	---
Lowell to Lawrence	Aug 64	14.0	2.0	0.4
Lawrence to Haverhill	Aug 64	14.4	---	---
Haverhill to Amesbury	Aug 64	62.1	40.0	---
Amesbury to Newburyport	Aug 64	29.5	8.8	---
MINIMUM		1.5	1.2	0.4
AVERAGE		29.6	13.0	3.4
MAXIMUM		62.1	40.0	6.5



COLIFORM DENSITY DECLINE
CONCORD TO MANCHESTER
SUMMER

FIGURE 22

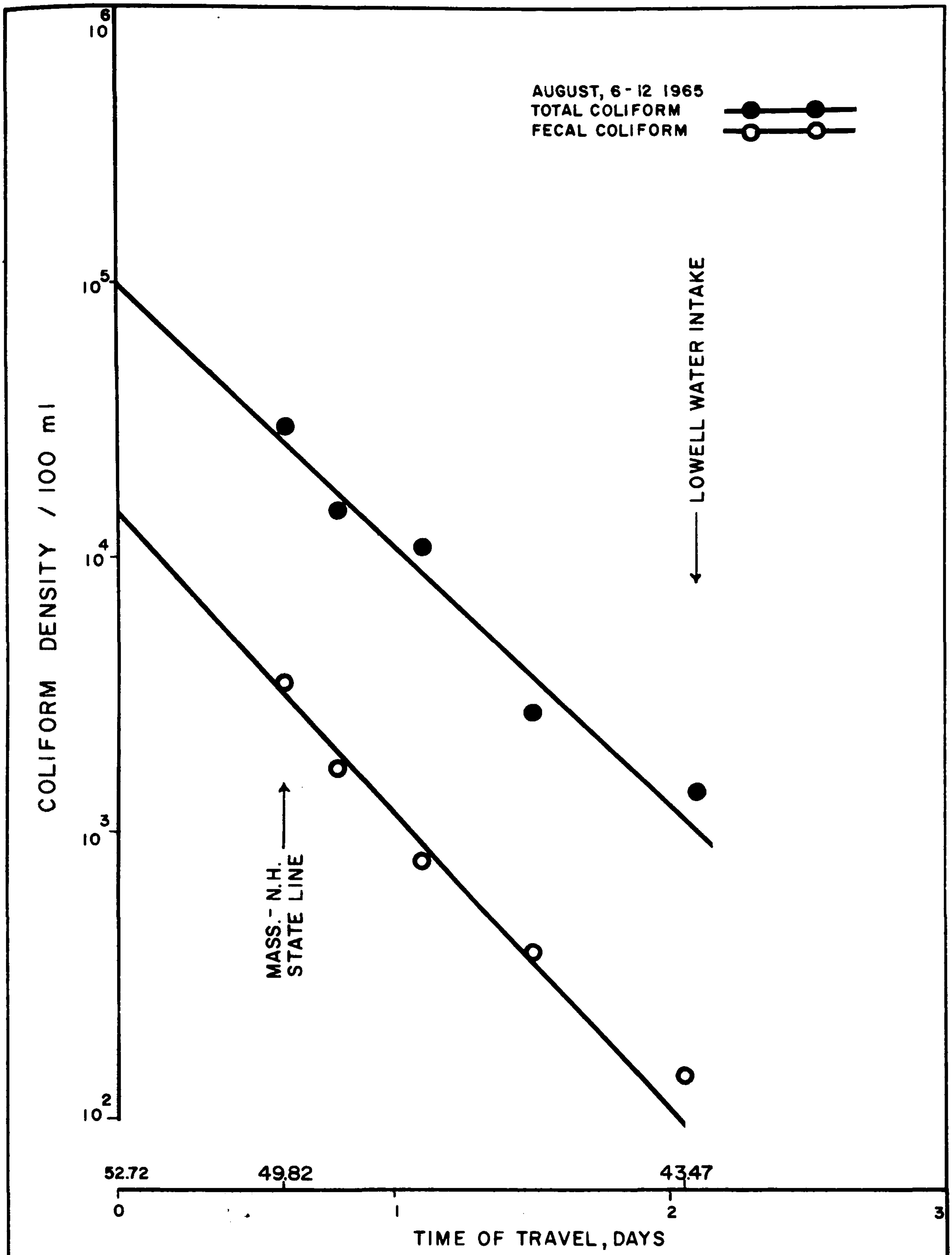


COLIFORM DENSITY DECLINE

MANCHESTER TO NASHUA

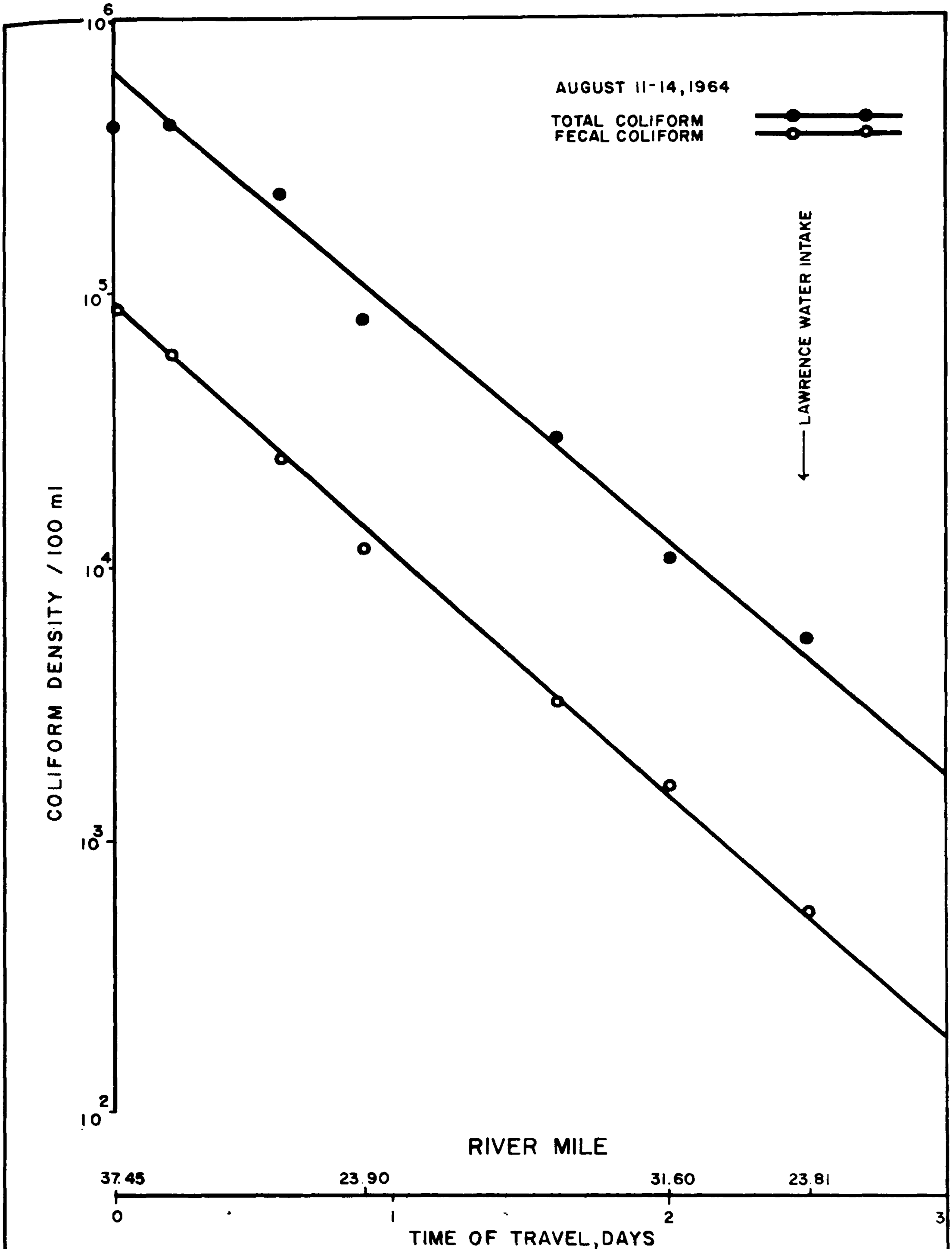
SUMMER

FIGURE 23



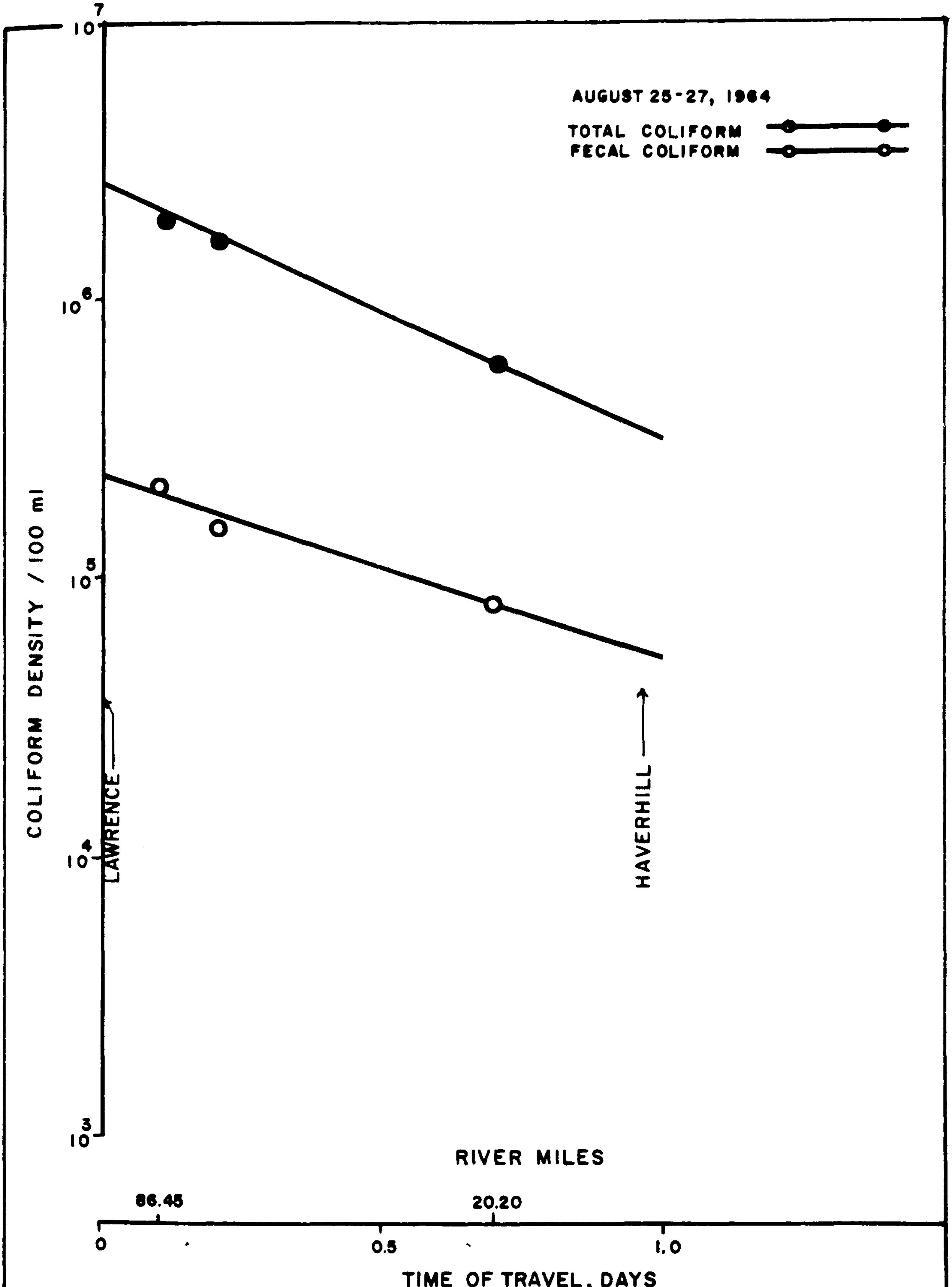
COLIFORM DENSITY DECLINE
NASHUA TO LOWELL
SUMMER

FIGURE 24



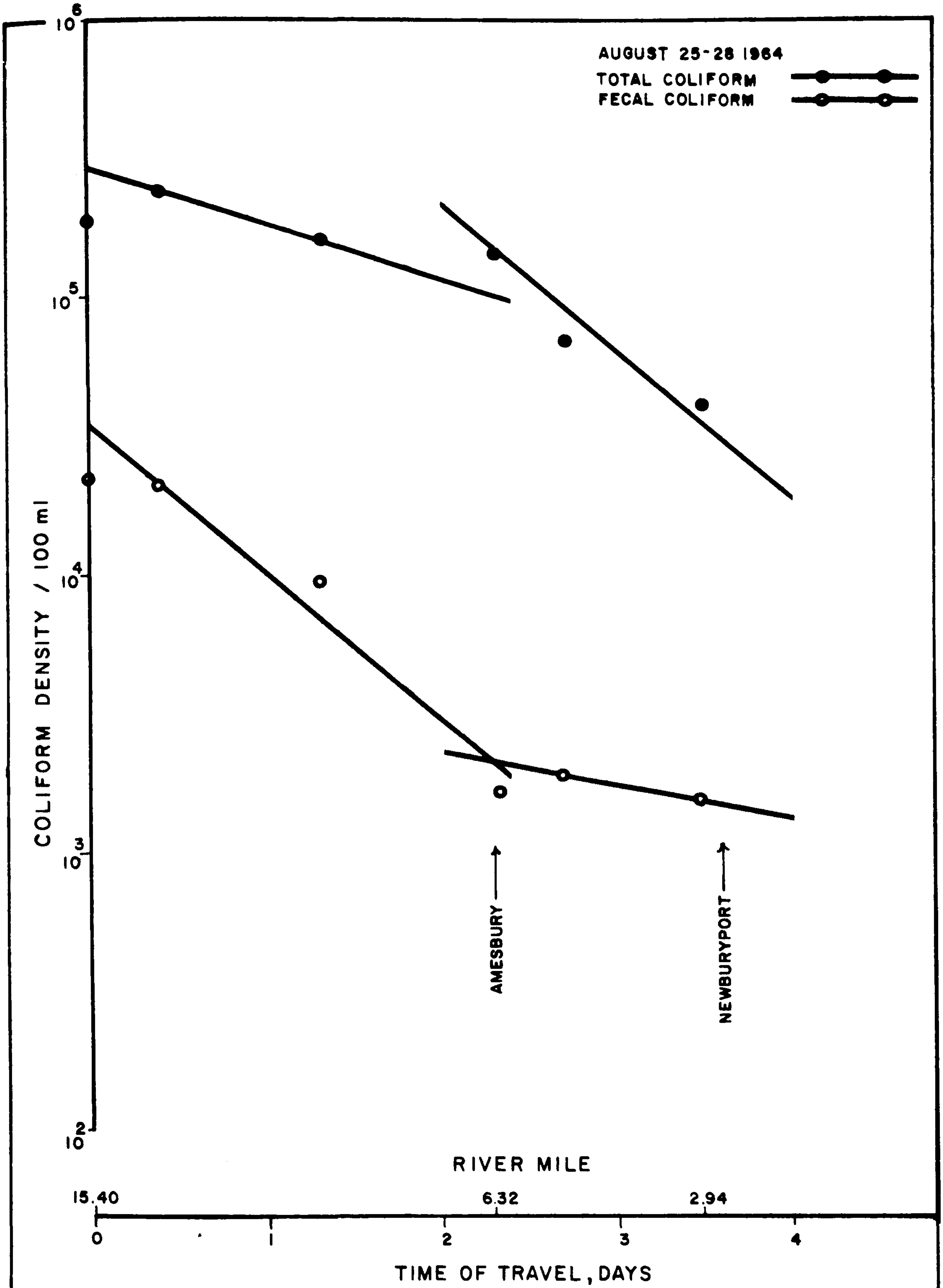
COLIFORM DENSITY DECLINE
LOWELL TO LAWRENCE
SUMMER

FIGURE 25



COLIFORM DENSITY DECLINE
LAWRENCE TO HAVERHILL
SUMMER

FIGURE 26

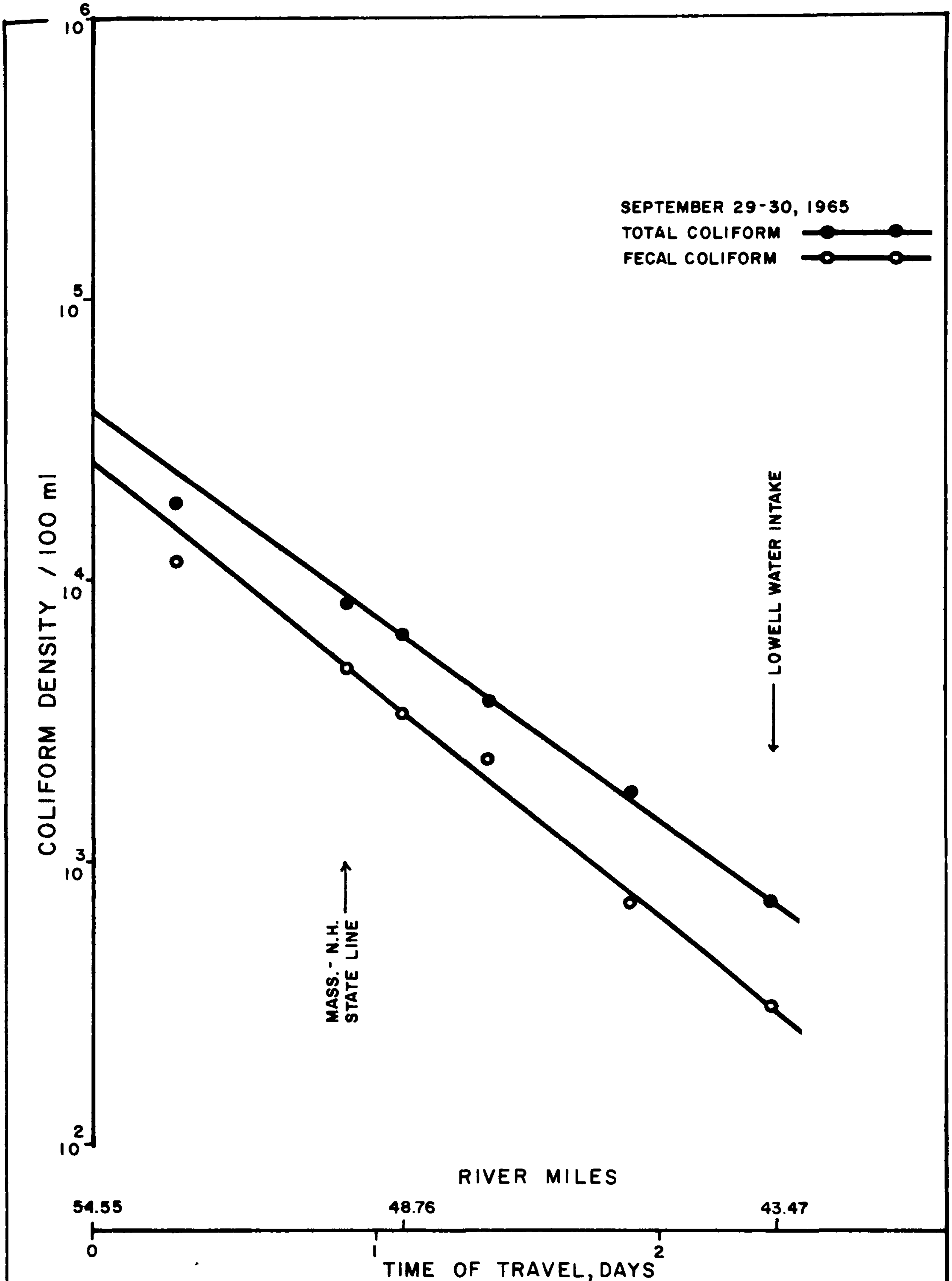


COLIFORM DENSITY DECLINE

HAVERHILL TO NEWBURYPORT

SUMMER

FIGURE 27

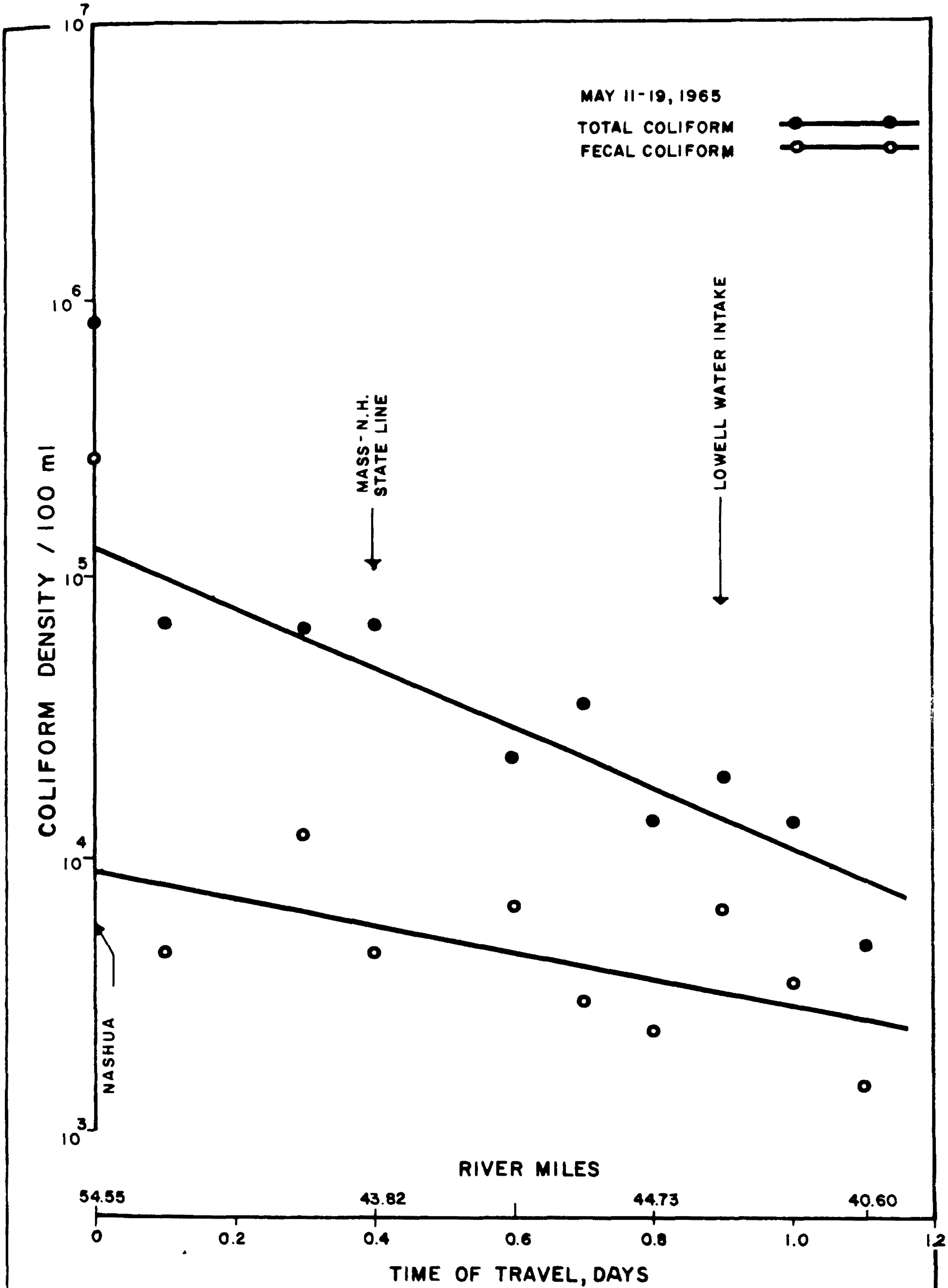


COLIFORM DENSITY DECLINE

NASHUA TO LOWELL

FALL

FIGURE 28



COLIFORM DENSITY DECLINE
NASHUA TO LOWELL
SPRING

FIGURE 29

TABLE 6

FECAL COLIFORM DENSITY DECLINE

Summer

MERRIMACK RIVER	DATE	FECAL COLIFORM DENSITY % Remaining After Daily Intervals		
		1 Day	2 Days	3 Days
Concord to Pembroke	Aug 65	30.0	9.1	---
Pembroke to Hooksett	Aug 65	44.8	---	---
Hooksett to Manchester	Aug 65	40.5	16.4	6.9
Manchester to Merrimack	Aug 65	1.6	---	---
Merrimack to Nashua	Aug 65	54.5	---	---
Nashua to Lowell	Aug 65	8.0	0.6	---
Lowell to Lawrence	Aug 64	12.7	1.7	0.2
Lawrence to Haverhill	Aug 64	23.9	---	---
Haverhill to Amesbury	Aug 64	26.3	8.6	---
Amesbury to Newburyport	Aug 64	77.4	60.9	---
MINIMUM		1.6	0.6	0.2
AVERAGE		32.0	16.2	3.6
MAXIMUM		77.4	60.9	6.9

was an increase in the rate of decline with increased coliform densities. The data reported here substantiates his findings. Other factors that affect the decline rate are mentioned above. Comparing Tables 5 and 6, it is seen that there is very little difference in the rate of decline for either total or fecal coliforms. The only exception occurs in the tidal area below Haverhill. In this reach, the "fresh water" portion of the estuary from Haverhill to Amesbury has a fecal coliform decline rate that is one-third that of the total coliforms. However, in the "brackish water" portion, from Amesbury to Newburyport, the trend is reversed; the fecal coliform decline rate is three times that of the total rate.

Table 7 compares the coliform density decline rates found between Nashua, New Hampshire, and Lowell, Massachusetts, during the spring, summer and fall months. The highest rate of decline, or lowest per cent remaining, occurs in May when the river flow is highest. The lowest rate is found during the lowest flow in September. Data obtained during the winter were not adequate to obtain a decline rate.

The values obtained for total coliform density decline rate are compared to values compiled by Kittrell and Furfari(12), as shown in Table 8. Values observed in the Merrimack River appear to be consistent with those reported by others.

Attempts have been made to assess the responsibility for pollution of the Merrimack River at key locations. Camp reported(15) that in 1935, two-thirds of the bacteria over the shellfish beds in the Merrimack River Estuary was attributed to the three downriver communities

TABLE 7

COMPARISON OF SEASONAL COLIFORM DENSITY DECLINE

Merrimack River, Nashua to Lowell

	Coliform Density % Remaining After Daily Intervals	
	1 Day	2 Days
TOTAL COLIFORMS		
May 1965	8.5	---
August 1965	11.0	1.2
September 1965	18.7	3.5
FECAL COLIFORMS		
May 1965	34.2	---
August 1965	8.0	0.6
September 1965	15.2	2.5

TABLE 8

COMPARISON OF TOTAL COLIFORM DENSITY DECLINE

RIVER	SEASON	TOTAL COLIFORM DENSITY % Remaining After Daily Intervals			
		1 Day	2 Days	3 Days	4 Days
Merrimack	Summer	29.6	13.0	3.4	---
Missouri	Summer	50	30	---	13
Ohio River	Summer	14-26	4-12	---	0.6-2.2
Tennessee (Knoxville)	Summer	35	12	---	2.3
Tennessee (Chattanooga)	Summer	25	7.4	---	0.95
Sacramento	Summer	17	4.8	---	---
Cumberland	Summer	3.6	1.3	---	---
Merrimack	Fall	18.7	3.5	---	---
Ohio	Winter	25-40	12-21	---	4.5-8.5
Merrimack	Spring	8.5	---	---	---

of Amesbury, Newburyport and Salisbury; Haverhill, Lawrence and Lowell were responsible for 29 per cent of the total.

Using the coliform density decline curves, an estimate was made of the coliforms reaching the Route 1 bridge in Newburyport from upstream communities. The contributions in August 1964 were: Amesbury 31.4 per cent, Haverhill Region 17.1 per cent, Lawrence Region 51.4 per cent and the remaining upstream communities 0.1 per cent.

Another area of interest is the New Hampshire-Massachusetts state line. The July-August 1965 studies indicated that Nashua and Hudson, New Hampshire, were responsible for 98.3 per cent, Merrimack 0.6 per cent and Manchester 1.1 per cent of the coliform bacteria at the state line. With the colder water temperature and longer survival time for the bacteria discharged upstream in November 1965, the proportion changed considerably. Under these circumstances about half the bacteria at the state line resulted from Nashua-Hudson discharges, about one-fourth from Manchester, one-sixth from discharges reaching the Merrimack River in the Merrimack, New Hampshire, area, and less than 1 per cent from discharges above Manchester, New Hampshire.

BACTERIA ON VEGETABLES

Water pumps were observed at many farms using the Merrimack River water for crop irrigation. Since high coliform densities were obtained for the river water, vegetables irrigated with this water were checked for the presence of fecal coliforms. For comparison, vegetables were obtained from farms that did not use Merrimack River water for irrigation.

The vegetables were purchased from roadside farm stands, as would an ordinary consumer, and placed into bags by the stand operator. Once the vegetables were in the laboratory they were handled with care to prevent contamination and were washed with sterile, buffered distilled water. The washings were tested for the presence of fecal coliforms. The results are shown in Table 9.

It should be noted that only those vegetables were tested that ordinarily are eaten without cooking. A significantly greater number of fecal coliforms were present on vegetables grown on those farms that used Merrimack River water for irrigation than on vegetables which were not.

SALMONELLA

While coliform densities indicate the magnitude of fecal pollution which may contain disease-producing organisms, detection of pathogenic Salmonella bacteria is positive proof that these organisms are actually present.

Salmonellosis, the disease caused by various species of salmonella bacteria, includes typhoid fever, gastroenteritis and diarrhea. There are more than 900 known serological types of Salmonella. During 1964 there were over 21,000 Salmonella isolations from humans in the United States and 57 known deaths resulting from Salmonellosis. Table 10 lists the ten most common Salmonella serotypes, clinical disease cases and carriers in the United States during 1964[16].

TABLE 9

BACTERIA ON VEGETABLES

VEGETABLES IRRIGATED WITH MERRIMACK RIVER WATER

	VEGETABLE	FECAL COLIFORM PRESENT
FARM A		
1.	Cucumber	Yes
2.	Cucumber	Yes
3.	6 carrots	Yes
4.	Bunch leaf lettuce	Yes
5.	Head lettuce	Yes
6.	Bunch radishes	Yes
7.	2 tomatoes	No
8.	1 pint strawberries	No
FARM B		
9.	Cucumber	Yes
10.	Cucumber	Yes
11.	Head lettuce	No
12.	Bunch radishes	Yes

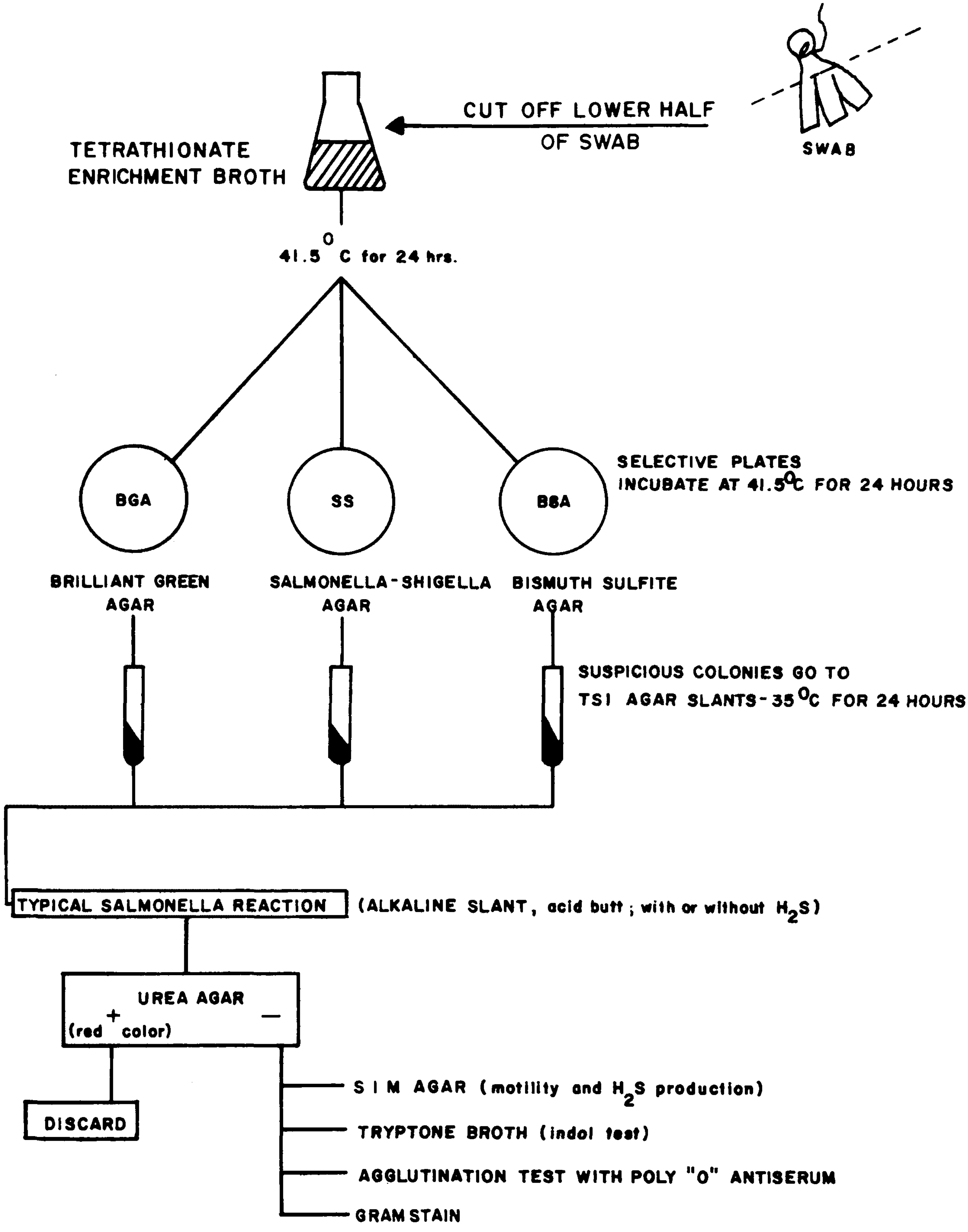
VEGETABLES NOT IRRIGATED WITH MERRIMACK RIVER WATER

	VEGETABLE	FECAL COLIFORM PRESENT
FARM C		
1.	2 tomatoes	No
2.	Bunch radishes with greens	Yes
3.	Head lettuce	No
FARM D		
4.	2 tomatoes	No
5.	Cucumber	No

TABLE 10

MOST FREQUENT SALMONELLA ISOLATIONS, 1964[16]

RANK	SEROTYPE	NUMBER	PERCENT	FOUND IN MERRIMACK RIVER BASIN
1.	S. typhimurium & S. typhimurium v. cop.	5,862	27.8	Yes
2.	S. derby	2,360	11.2	Yes
3.	S. heidelberg	1,717	8.1	Yes
4.	S. infantis	1,523	7.2	Yes
5.	S. newport	1,036	4.9	Yes
6.	S. enteritidis	801	3.8	Yes
7.	S. typhi	703	3.3	No
8.	S. saint-paul	645	3.1	Yes
9.	S. oranienburg	550	2.6	Yes
10.	S. montevideo	524	2.5	Yes
	TOTAL	15,721	74.5	
	TOTAL (all serotypes)	21,113	100.0	



SCHEMATIC OF SALMONELLAE ISOLATION PROCEDURE

FIGURE 30

The ever present danger of such infectious water-borne diseases was dramatically illustrated in May 1965 when 18,000 residents of Riverside, California, were suddenly afflicted with acute gastroenteritis. Three died and 200 were hospitalized. It was shown that the outbreak was caused by Salmonella typhimurium which was transmitted through the municipal water supply(17).

To demonstrate the presence of Salmonella in Merrimack River waters, gauze swabs were suspended in the flowing waters at key locations. After about five days the swabs were removed and tested for the presence of Salmonella. The procedure for growing and isolating the Salmonellae was a modification of the method used by Spino(18). A schematic diagram of the steps used is shown in Figure 30. After suspected colonies were obtained, confirmation and identification of the serotype was performed by the Communicable Disease Center in Atlanta, Georgia. Results, showing the type of Salmonella isolated and corresponding coliform density, are presented in Table 11.

Enteric pathogens of the genus Salmonella were consistently recovered from the Merrimack River both in New Hampshire and Massachusetts, indicating that ingestion of any water from the Merrimack River is a definite health hazard. Salmonella organisms were isolated during each test made at the Lowell and Lawrence, Massachusetts, water intakes. Altogether, twenty-one serotypes were recovered from fifty-four isolations. These disease organisms were found in river water having a total coliform density (MF) as low as 180 per 100 ml.

A test of the Newburyport, Massachusetts, sewage treatment

TABLE 11

SALMONELLA ORGANISMS

STATION	DESCRIPTION	RIVER MILE	DATE WITHDRAWN	SALMONELLA PRESENT	MPN TOTAL COLIFORM	MPN FECAL COLIFORM	MF TOTAL COLIFORM	MF FECAL COLIFORM
FC-3.0	Merrimack R. at Sewalls Falls Dam	97.83	7-14-65	Not detected	---	---	---	---
			10-18-65	Not detected	---	---	200	140
			10-27-65	S. typhimurium	490	490	180	180
			11- 8-65	Not detected	900	700	830	830
			11-29-65	S. typhimurium	790	790	300	300
			12-20-65	S. oranienburg	---	---	700	590
CH-1.0	Merrimack R. at Garvin's Falls Dam	86.80	9-27-65	S. enteritidis S. newington	---	---	1,170	1,170
			11- 8-65	S. infantis	4,900	3,300	5,700	5,700
			11-29-65	S. infantis	2,000	2,000	800	800
HM-1.7	Merrimack R.	75.85	12-20-65	S. heidelberg S. infantis	---	---	600	440
HM-1.8	Merrimack R.	75.75	11- 8-65	S. heidelberg	1,090	700	590	590

TABLE 11 (Continued)

SALMONELLA ORGANISMS

STATION	DESCRIPTION	RIVER MILE	DATE WITHDRAWN	SALMONELLA PRESENT	MPN TOTAL COLIFORM	MPN FECAL COLIFORM	MF TOTAL COLIFORM	MF FECAL COLIFORM
HM-2.7	Merrimack R. at Amoskeag Ski Dock	73.57	7-14-65	Not detected	---	---	---	---
			9-27-65	S. cubana	---	---	320	320
			10-18-65	S. heidelberg	---	---	380	380
			10-27-65	S. reading	1,300	1,300	942	942
MN-2.0	Merrimack R. at Goff's Falls	68.05	7-14-65	S. tennessee S. infantis S. heidelberg	---	---	---	---
			10-18-65	S. heidelberg	---	---	4,000	1,100
			10-27-65	S. typhimurium	16,000	16,000	3,500	3,500
NL-2.0	Merrimack R. at Lowell Boat Club, Foot of Lakeview Ave.	48.76	7-14-65	S. muenster	---	---	---	---

TABLE 11 (Contimued)

SALMONELLA ORGANISMS

STATION	DESCRIPTION	RIVER MILE	DATE WITHDRAWN	SALMONELLA PRESENT	MPN TOTAL COLIFORM	MPN FECAL COLIFORM	MF TOTAL COLIFORM	MF FECAL COLIFORM
NL-2.5	Merrimack R. at Robinson's Landing	48.15	10-18-65	S. new brunswick S. infantis	---	---	1,790	1,790
			10-27-65	S. heidelberg	2,400	2,400	1,590	1,590
			11- 8-65	S. st. paul S. blockley	9,200	9,200	2,920	2,920
NL-4.0	Merrimack R. at Lowell Water Intake	43.47	6-24-65	S. typhimurium S. newport	---	---	---	---
			7-14-65	S. muenster	---	---	---	---
			9-27-65	S. typhimurium	---	---	1,000	100
			10-18-65	S. heidelberg	---	---	370	370
			10-27-65	S. new brunswick	3,480	1,090	540	540
			11- 8-65	S. st. paul S. typhimurium	3,480	1,720	700	520

TABLE 11 (Continued)

SALMONELLA ORGANISMS

STATION	DESCRIPTION	RIVER MILE	DATE WITHDRAWN	SALMONELLA PRESENT	MPN TOTAL COLIFORM	MPN FECAL COLIFORM	MF TOTAL COLIFORM	MF FECAL COLIFORM
LL-7.0	Merrimack R. at Lawrence Water Intake	29.81	6-24-65	S. oranienburg S. newport	---	---	---	---
			7-14-65	S. bareilly	---	---	---	---
			9-27-65	S. newport	---	---	1,000	200
			10-18-65	S. infantis S. montevideo S. binza S. typhimurium	---	---	1,700	1,200
			10-27-65	S. heidelberg	3,480	2,400	800	800
			11- 8-65	S. heidelberg	490	490	400	310
HN-1.0	Merrimack R. at Haverhill River-side Airport	15.40	11-29-65	S. infantis S. hartford S. senftenburg	22,000	22,000	5,000	5,000

TABLE 11 (Continued)

SALMONELLA ORGANISMS

STATION	DESCRIPTION	RIVER MILE	DATE WITHDRAWN	SALMONELLA PRESENT	MPN TOTAL COLIFORM	MPN FECAL COLIFORM	MF TOTAL COLIFORM	MF FECAL COLIFORM
So-9.0	Souhegan R. at Everett Turnpike (Fast flow)	0.8	7-14-65	Not detected	---	---	---	---
			9-27-65	Not detected	---	---	< 100	10
			10-27-65	Not detected	50	50	8	8
			11-29-65	Not detected	5,420	3,480	2,400	2,400
			12-20-65	Not detected	---	---	120	120
So-9.0	Souhegan R. below Everett Turnpike (slow flow)	0.8	12-20-65	Not detected	---	---	120	< 10
NN-2.2	N. Nashua R. at Ponakin Mill Bridge (36.6 mi. above mouth of Nashua R.)	3.1	11- 8-65	Not detected	1,700	1,700	1,300	1,300
			11-29-65	S. new brunswick	34,800	34,800	9,600	9,600
			12-20-65	S. montevideo	---	---	42,000	16,500

TABLE 11 (Continued)

SALMONELLA ORGANISMS

STATION	DESCRIPTION	RIVER MILE	DATE WITHDRAWN	SALMONELLA PRESENT	MPN TOTAL COLIFORM	MPN FECAL COLIFORM	MF TOTAL COLIFORM	MF FECAL COLIFORM
SN-1.5	South Branch Nashua River at Thayer Bridge (34.5 mi. above mouth of Nashua R.)	1.0	11-29-65	S. livingstone S. typhimurium	160,000	160,000	337,000	337,000
			12-20-65	S. typhimurium-var. copenhagen S. blockley	---	---	90,000	14,000
L.E.S.	Sewer on North Side of Lawrence Experiment Station	---	6-24-65	S. cubana	---	---	---	---
---	Effluent from Newburyport Sewage Treatment Plant	2.23	4-18-66	S. chester S. oranienburg	*	*	*	*

* Intermittent chlorination during six days swab was in effluent channel, including last 2 1/2 hours. Coliforms (MPN) ranged from 16,000,000 total and 3,480,000 fecal per 100 ml when raw sewage was being discharged from the plant to 490 total and 40 fecal per 100 ml at time swab was removed.

plant effluent taken during intermittent chlorination indicated that this method of disinfection was not effective in killing the pathogens present.

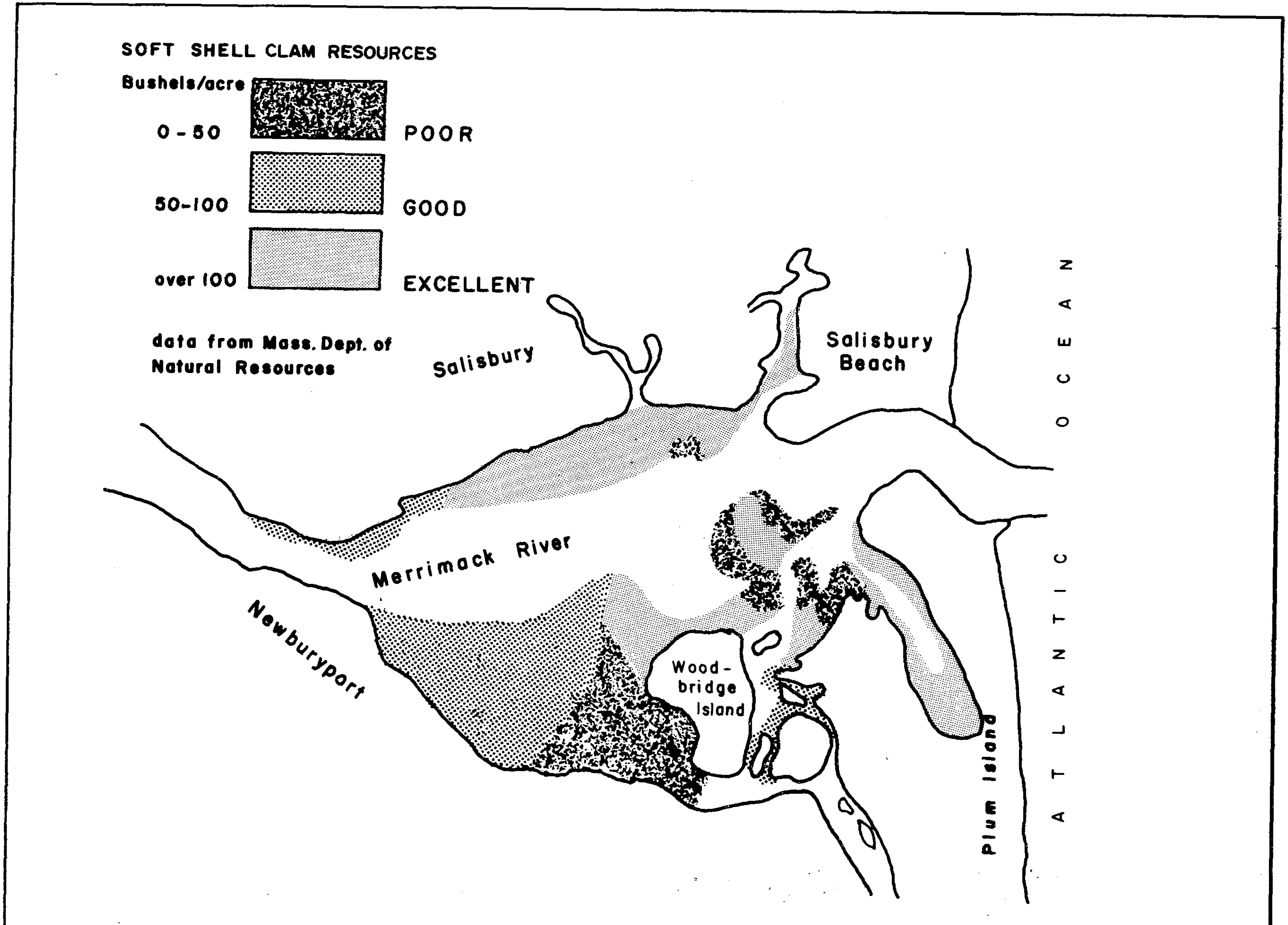
Salmonellae were consistently found just below the New Hampshire-Massachusetts state line even when the level of coliforms was relatively low. Thus, waters flowing into Massachusetts from New Hampshire endanger the health of persons in Massachusetts.

BACTERIA IN THE ESTUARY

In this section of the report, the estuary is considered to be that portion of the Merrimack River below the railroad bridge, Station HN-6.0, at river mile 2.94. Bacterial densities in this area are effected by the bacterial load of the Merrimack River and the bacterial discharge from the Newburyport sewage treatment plant.

The distance from the lighthouse on Plum Island to the railroad bridge is 2.94 miles, and the widest point is 1.8 miles at mean high water. The range between mean high water and mean low water is eight feet. At mean low tide the surface area of the estuary is decreased to 53 per cent of its high tide area. This results in a high rate of flushing and dilution.

Over 4,000 acres of salt marsh drain into the estuary; and 747 acres of intertidal area are available for shellfish harvest. Figure 31 shows the location of the shellfish beds and relative productivity of each. The Division of Marine Fisheries, Commonwealth of Massachusetts, found that an acre of shellfish beds in this area contains



LOCATION OF SHELLFISH FLATS MERRIMACK RIVER ESTUARY

FIGURE 31

an average of 100 bushels of legal-size clams.

Dispersion studies were carried out using Rhodamine B dye to determine the flow characteristics of the estuary and the direction that waste discharges containing bacteria would travel. It was found that sewage discharged at Amesbury would reach the shellfish beds in the estuary on the outgoing tide. Dye releases in Plum Island River indicated that Pine Island Creek is the point from which water flows north through Plum Island River to the Merrimack River and south through Plum Island River to the Parker River. Coliform bacteria data presented in Table 12 confirm that Pine Island Creek is the division of north-south flow in the Pine Island River. In Black Rock Creek, releases of dye indicated that the effluent from the Salisbury Beach septic tank would be carried over the shellfish beds. A graphic presentation of the dye releases in Plum Island River and Black Rock Creek is shown in Figure 32.

In Black Rock Creek the coliform densities were very high. A significant number of these coliforms enter the Merrimack River estuary. These data are presented in Table 13. Without additional treatment, or, preferably, complete removal of waste discharges from the estuary, the productive shellfish beds at the mouth of Black Rock Creek can not be opened for harvest of shellfish for human consumption.

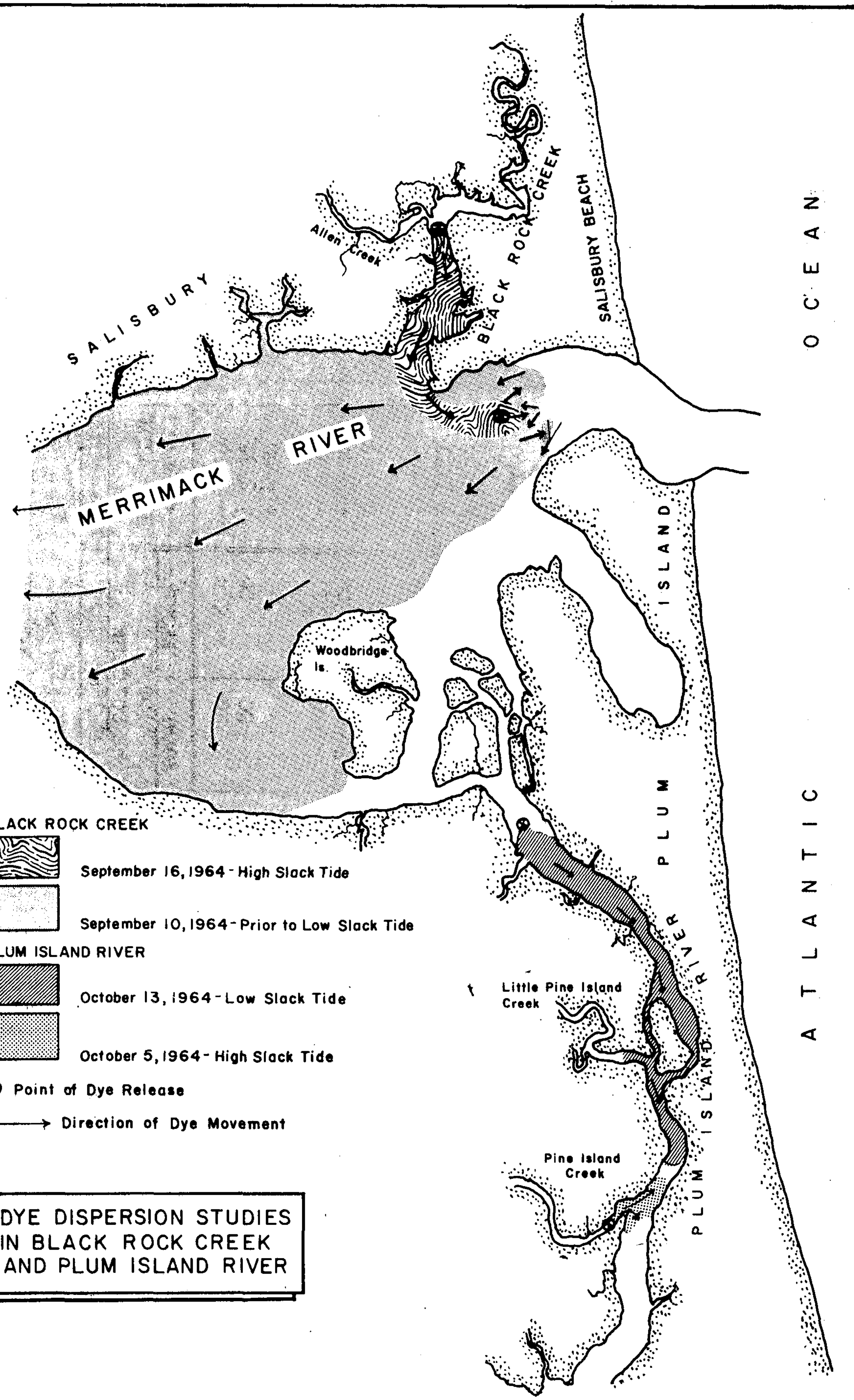
Near the end of the summer of 1964, the City of Newburyport completed construction of a primary sewage treatment plant. The effluent from this plant is spread over the shellfish growing areas

TABLE 12

COLIFORM VALUES IN PLUM ISLAND RIVER

STATION	TOTAL COLIFORMS MPN per 100 ml		FECAL COLIFORMS MPN per 100 ml	
	10/5/64	10/6/64	10/5/64	10/6/64
R-6A	220	130	80	< 20
R-6B	130	70	< 20	< 20
R-6C	220	80	50	20
R-6D	2,400	230	230	80
R-6E	230	80	20	< 20
R-6F	790	490	170	80
R-6G	110	40	< 20	20
R-6H	20	< 20	20	< 20
R-6I	< 20	< 20	< 20	< 20
R-6J	< 20	20	< 20	< 20

Station Latitude and Longitude are found in Appendix A, page A-12.



BLACK ROCK CREEK

September 16, 1964 - High Slack Tide

September 10, 1964 - Prior to Low Slack Tide

PLUM ISLAND RIVER

October 13, 1964 - Low Slack Tide

October 5, 1964 - High Slack Tide

⊗ Point of Dye Release

⟶ Direction of Dye Movement

DYE DISPERSION STUDIES IN BLACK ROCK CREEK AND PLUM ISLAND RIVER

FIGURE 32

TABLE 13

COLIFORM VALUES IN BLACK ROCK CREEK
July, 1965

STATION	JULY 12, 1965 LOW TIDE + HOURS	JULY 12, 1965 MF COLIFORM /100 ml TOTAL	JULY 12, 1965 MF COLIFORM /100 ml FECAL	JULY 15, 1965 HIGH TIDE + HOURS	JULY 15, 1965 MF COLIFORM /100 ml TOTAL	JULY 15, 1965 MF COLIFORM /100 ml FECAL	JULY 22, 1965 HIGH TIDE + HOURS	JULY 22, 1965 MF COLIFORM /100 ml TOTAL	JULY 22, 1965 MF COLIFORM /100 ml FECAL
R-4A	+ 4:20	<100	<10	+ 0:57	20	< 4	+ 2:50	2,000	360
	+ 5:40	<100	<10	+ 2:27	80	28	+ 3:35	4,000	900
	--	--	--	--	--	--	+ 4:50	3,600	700
R-4AA	+ 4:15	<100	10	+ 0:52	140	112	+ 2:45	8,800	2,360
	+ 5:35	<100	20	+ 2:24	>8,000	>2,800	+ 3:30	9,100	3,070
	--	--	--	--	--	--	+ 4:45	75,000	13,200
R-4BB	+ 4:10	500	210	+ 0:47	>10,000	>8,000	+ 2:45	65,000	13,700
	+ 5:30	300	70	+ 2:22	>12,000	>5,000	+ 3:25	95,000	28,100
	--	--	--	--	--	--	+ 4:35	230,000	>50,000
R-4CC	+ 4:05	4,000	600	+ 0:42	25,000	> 5,000	+ 2:40	136,000	64,400
	+ 5:25	300	70	+ 2:17	>50,000	>10,000	+ 3:25	250,000	>50,000
	--	--	--	--	--	--	+ 4:35	>300,000	>50,000
R-4DD	--	--	--	--	--	--	+ 2:40	14,500,000	1,490,000
	--	--	--	--	--	--	+ 3:25	19,000,000	1,240,000
	--	--	--	--	--	--	+ 4:30	23,000,000	1,500,000

Station Latitude and Longitude are found in Appendix A, page A-12.

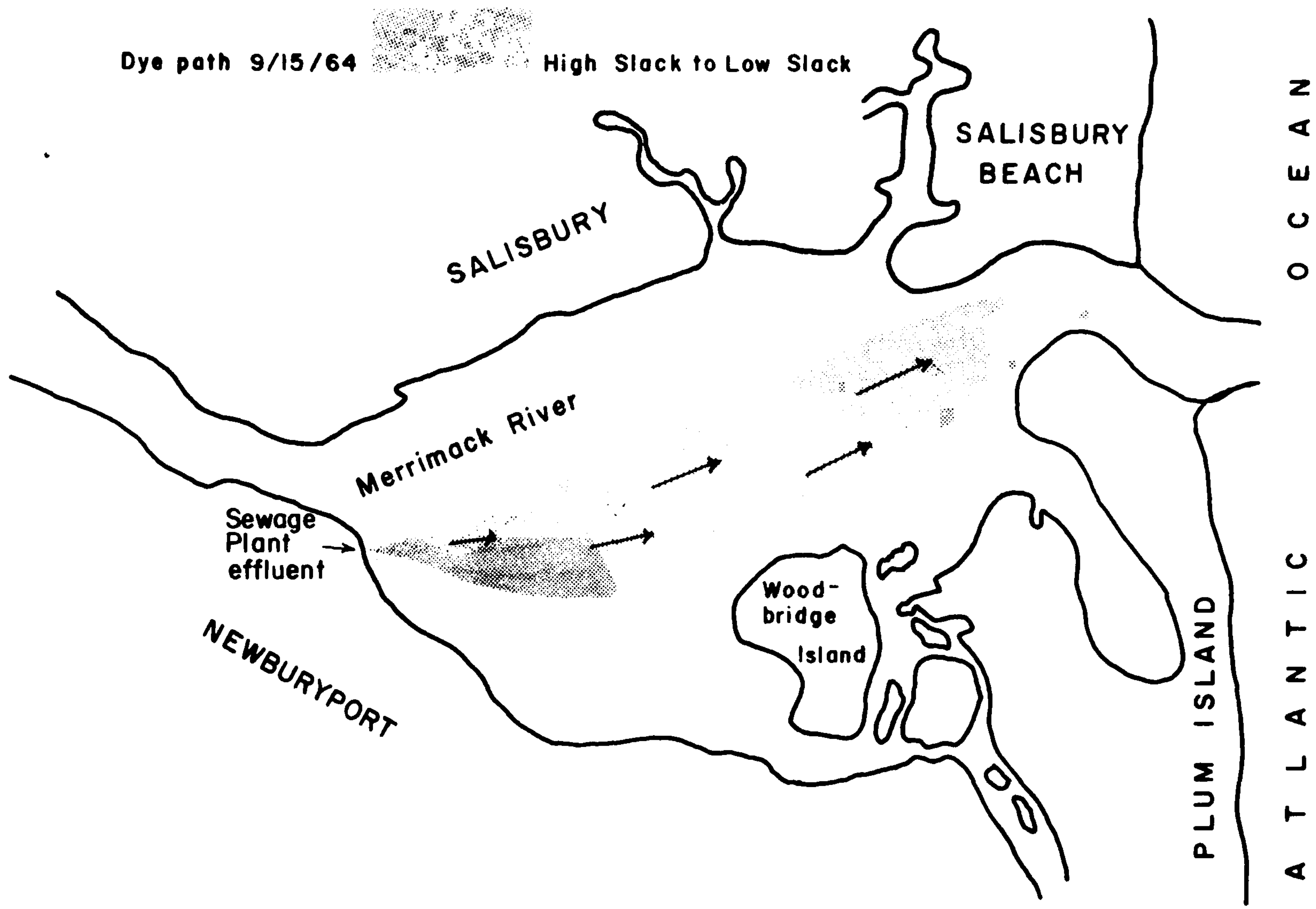
during each tidal cycle, as shown by dye releases. Figure 33 shows the path taken on the outgoing tide by the dye released at the treatment plant effluent. When the tide began to flood, nearly all the estuary was covered by the dye.

At three different times, September 15-16, 1964, October 19-20, 1964, and June 8 and 10, 1965, bacterial analyses were made of the Merrimack River estuary. Each time the Newburyport sewage treatment plant was either not operating properly or the sewage was bypassing the treatment plant. The sampling station locations are given in Appendix A, page A-12, and the bacterial densities are found in Appendix C. As expected, the variation in coliform values throughout the estuary was considerable. However, when comparing stations, those with high values were consistently high. The total coliform values obtained at low tide were averaged for each station. The same was done for high tide values. Using these coliform results and the dye dispersion results, an estimate of the lines of equal coliform density was plotted, as shown in Figures 34 and 35.

Levels of contamination used to classify waters over shellfish growing areas in Massachusetts are:

DEGREE OF CONTAMINATION OF OVERLAYING WATER

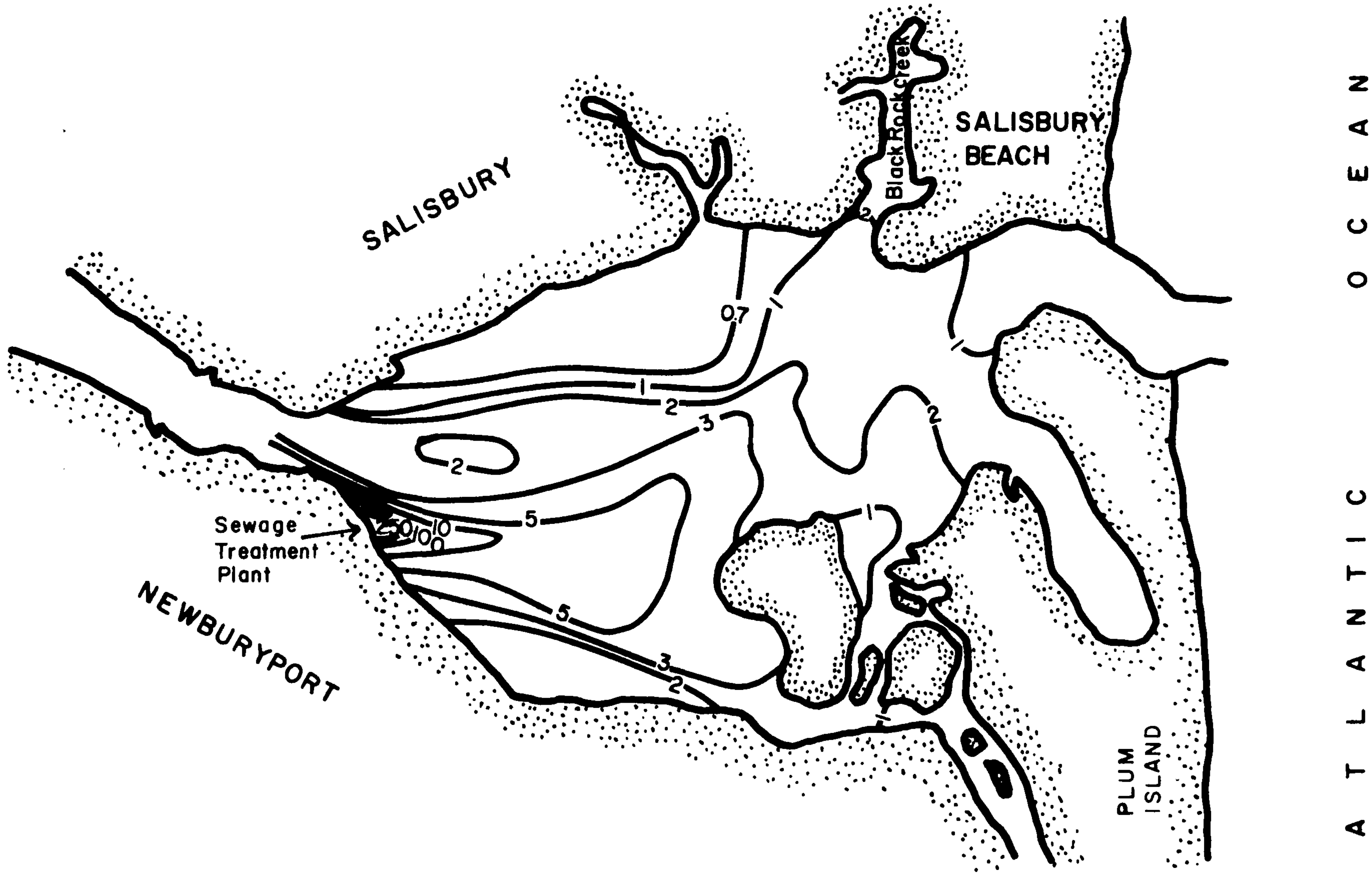
0-70	per 100 ml - clean
71-700	per 100 ml - moderately contaminated
over 700	per 100 ml - grossly contaminated



DYE DISPERSION IN MERRIMACK RIVER ESTUARY - 9/15/64

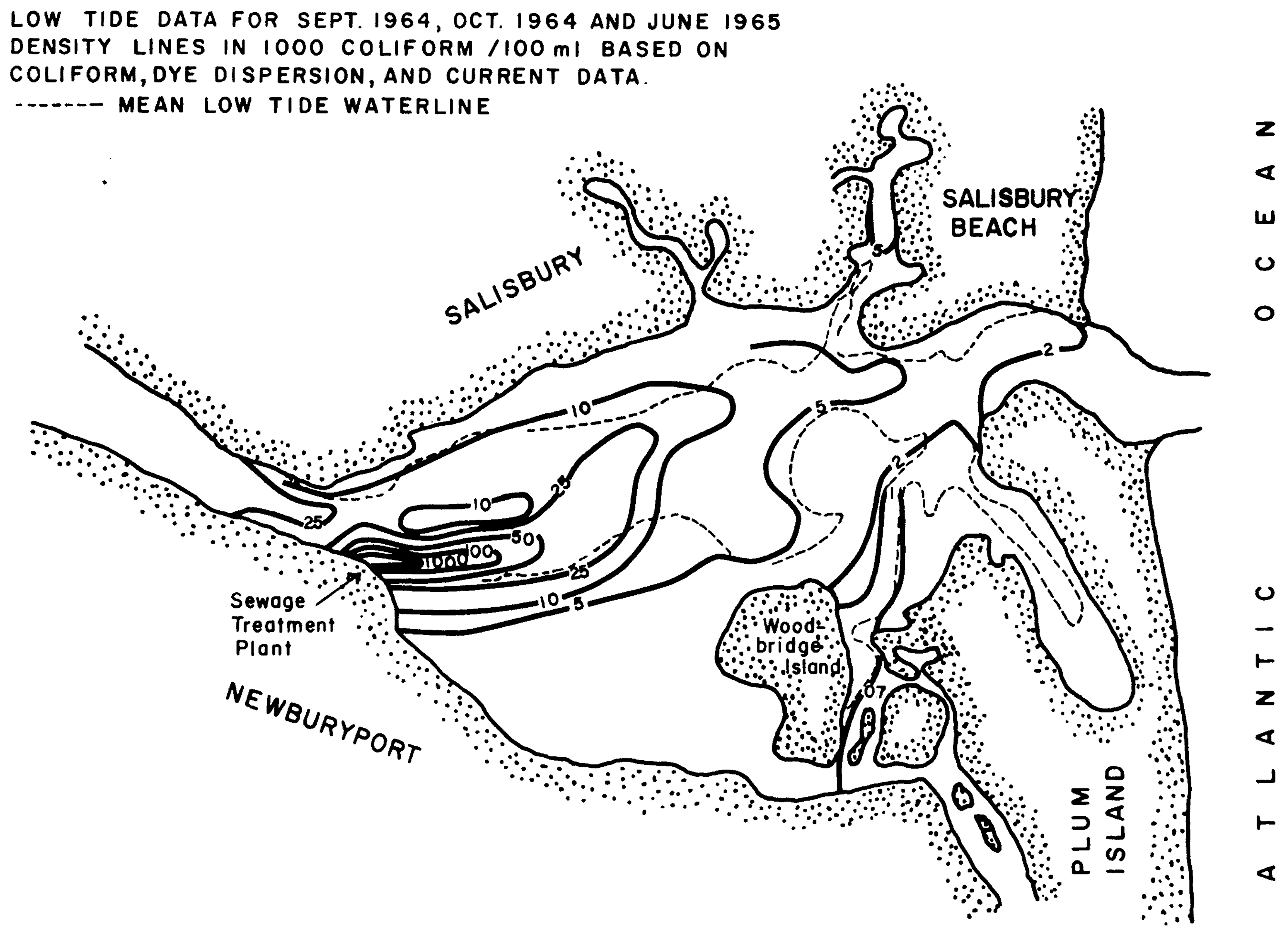
FIGURE 33

HIGH TIDE DATA FOR SEPT. 1964, OCT. 1964 AND JUNE 1965
DENSITY LINES IN 1000 COLIFORMS /100 ml
BASED ON COLIFORM, DYE DISPERSIONS, AND CURRENT DATA



TOTAL COLIFORMS IN MERRIMACK RIVER ESTUARY - HIGH TIDE

FIGURE 34



TOTAL COLIFORMS IN MERRIMACK RIVER ESTUARY - LOW TIDE

FIGURE 35

When these standards were applied to the Merrimack River estuary high tide data, as shown in Figure 34, it was found that most of the area was grossly contaminated, only a small area of the Salisbury flats being moderately contaminated. A very small area in Plum Island River can be considered moderately contaminated during low tide, as shown in Figure 35. The data also show that the effluent from the Newburyport sewage treatment plant has a significant effect on the bacterial densities in the estuary when the plant is not operating properly.

NITROGEN AND PHOSPHORUS

With proper environmental conditions, a nuisance can be created in a stream by large growths of algae or other aquatic vegetation. Aquatic plants can become so thick that they are esthetically displeasing and render the stream unfit for many water uses. At times the algal growths are killed and decay within or along the banks of the river, causing very unpleasant odors. Dense growths of algae may not only have a direct effect on water uses of a river, but may also reduce the dissolved oxygen to levels that are below the minimum required by aquatic life.

Oxygen is generated by the algae when there is sunlight, but, in the absence of sunlight, algal respiration depresses the oxygen levels to low values. This may occur not only at night but also on cloudy days.

Algae and other aquatic plants tend to develop in slow moving streams when the concentrations of key nutrients that are required for growth are present in sufficient amounts. Among the nutrients, nitrogen and phosphorus play dominant roles.

Nitrogen, in the forms of ammonia, organic and nitrate, is added to the Merrimack River by domestic and industrial wastes. A major source of nitrogen was the Hampshire Chemical Co., at Nashua, New Hampshire. Occasional releases of ammonia from this facility have occurred over the past years. However, corrective measures have been taken by the company to prevent further additions to the river.

Values for nitrogen compounds in the Merrimack River were 0.4 to 3.5 mg/l for ammonia, 0.43 to 5.58 mg/l for organic nitrogen, and 0.00 to 0.8 mg/l for nitrate. All values reported are as nitrogen. Appendix B contains a summary of observed data. Considerable fluctuations are found in the values, resulting from uptake and release of the nutrients as stream life fluctuates. Values for September 14-16, 1965, are indicative of the general trend of nitrogen expected in the Merrimack River. Values above Concord are 0.47 mg/l of ammonia, which increases to 0.57 mg/l below the city. Below Manchester, ammonia increases to 1.10 mg/l, reaching a value of 1.73 mg/l below Nashua. A similar trend is present in most of the other data, indicating the increase to the nutrient load by each city.

Values of ammonia, albuminoid and nitrate nitrogen from June to November for the years 1887 through 1908 are summarized and compared to the data of 1964-1965 in Table 14. Albuminoid nitrogen is included in the organic nitrogen test used in 1964 and 1965 and is the major portion of the reported value. In the Merrimack River drainage basin, population increased from 640,000 in 1900 to 1,072,000 in 1960, an increase of 67 per cent. During this same time period, the ammonia concentration had increased by 1,900 per cent, albuminoid or organic nitrogen by 1,200 per cent, and nitrate by 2,400 per cent.

TABLE 14

COMPARISON OF NITROGEN VALUES

YEARS	STATION	NITROGEN as N AMMONIA	ALBUMINOID OR ORGANIC	NITRATE
1887-1908	Above Lowell	0.04	0.15	0.02
1887-1908	Above Lawrence	0.10	0.19	0.02
1964-1965	NL-2.0, 3.0, and 4.0	0.8	1.92	0.5
1964-1965	LL-7.0	0.9	—	—

Average orthophosphate values of the Merrimack River are shown in Appendix B. Individual values varied from 0.04 to 2.17 mg/l, as phosphate. Phosphate values also showed a trend towards increasing levels below each city, with Concord, Manchester and Nashua each contributing significant amounts of phosphate to the waters entering Massachusetts.

The phosphate content of several tributaries are summarized in Appendix E. Values for these tributaries ranged from a high of 33.9 mg/l to a low of 0.03 mg/l of total phosphate as PO_4, with the average concentration 1.88 mg/l. Except for the extremely high values, the tributary phosphate values were of the same order of magnitude as those observed in the Merrimack River.

The Merrimack River and tributary values for both phosphate and nitrogen were in considerable excess of the minimum needed to produce growths of nuisance algae. These high values are an indication of the need for nutrient removal facilities in the Merrimack River Basin.

INDUSTRIAL WASTES

Industrial waste data, presented in Table 3 were based primarily upon information provided by the states of New Hampshire and Massachusetts. A limited number of industrial waste studies were conducted to obtain supplementary information where necessary. These data are shown in Appendix D. Industries surveyed and the areas of interest were Hampshire Chemical Corporation, Nashua, New Hampshire—ammonia; New England Pole and Wood Treating Corporation, Merrimack, New Hampshire—phenol and BOD; Foster Grant Company, Manchester, New Hampshire—BOD; and French Bros. Beef Company, Hooksett, New Hampshire—BOD and solids.

Following the industrial effluent sampling and a discussion of findings with industrial officials, the Hampshire Chemical Corporation and the New England Pole and Wood Treating Corporation took steps to substantially reduce their wastes to the Merrimack River.

CHLORIDES

Chloride determinations were carried out on the Merrimack

River from Haverhill to Newburyport. Table 15 and Figure 36 show the high tide, low tide and an average of the high and low tide values at each sampling point. The chloride samples at different depths indicated that there was good vertical mixing of the salt and fresh water in the tidal section of the river. This is consistent with the findings of the dye dispersion studies.

TABLE 15

CHLORIDE RESULTS FOR MERRIMACK RIVER
AUGUST 25-28, 1964

STATION	RIVER MILE	HIGH TIDE, PPM			LOW TIDE, PPM			AVERAGE PPM
		MAX.	AVG.	MIN.	MAX.	AVG.	MIN.	
HN-1.0	15.40	22	21	20	20	20	20	20
HN-2.0	13.47	35	26	22	25	20	20	23
HN-3.0	10.36	500	220	35	20	20	20	120
HN-4.0	6.92	10,000	6,400	1,400	120	66	30	3,230
HN-5.0	5.50	14,000	11,000	9,000	400	195	40	5,600
HN-6.0	2.94	17,000	16,700	16,000	4,000	2,500	500	9,600

Solubility of oxygen in water is affected by the chloride content of the water. The solubility of oxygen in 25°C water containing no chlorides is 8.38 ppm, while at 5,000 ppm chlorides, the solubility of oxygen is reduced by 5.0 per cent to 7.96 ppm in water of the same temperature.

TRIBUTARIES

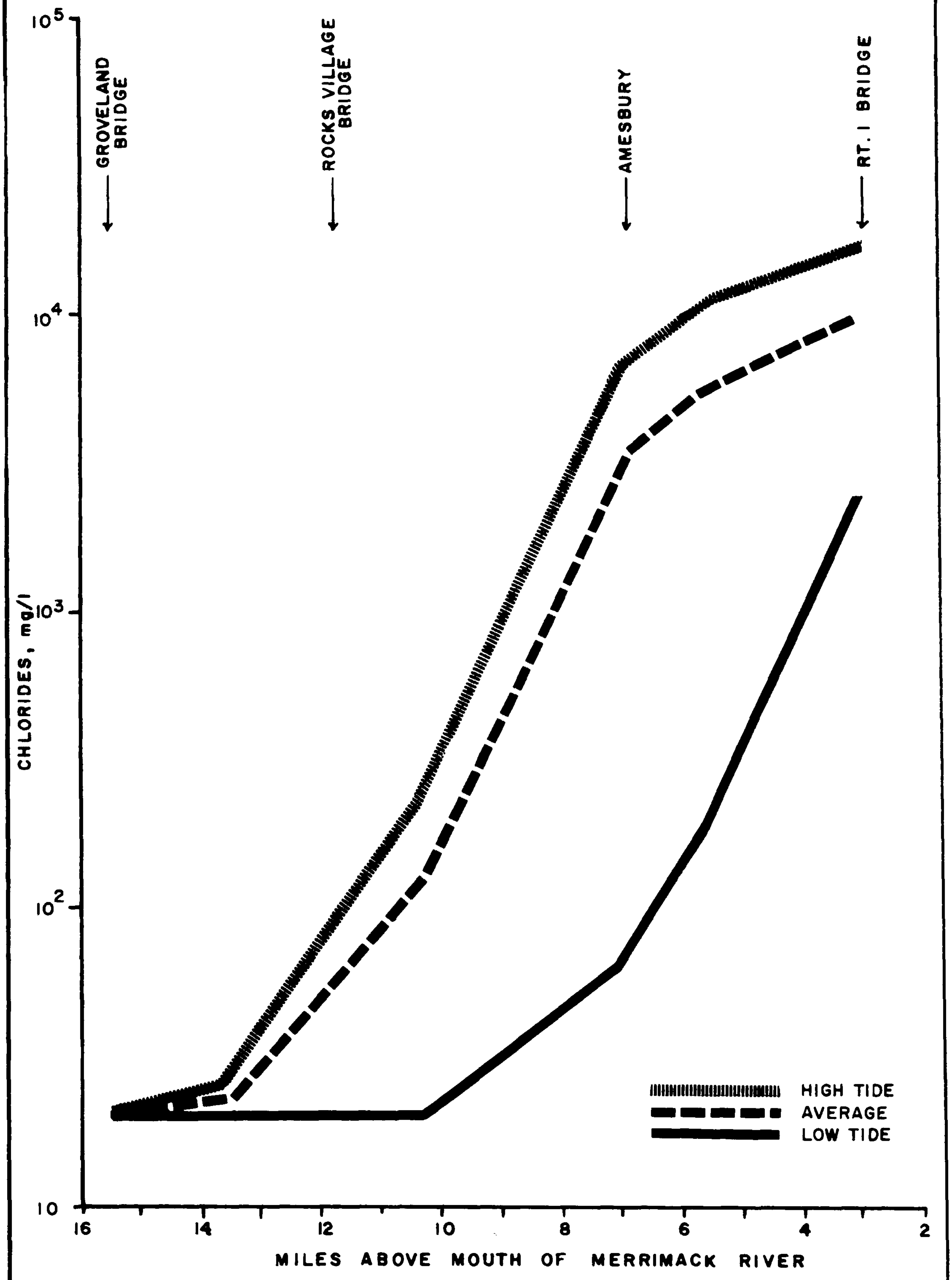
Souhegan River

The Souhegan River rises in Massachusetts and flows northeast through Greenville, New Hampshire, to Wilton, where it is joined by Stony Brook. From Wilton it travels in an easterly direction through Milford, Amherst and Merrimack, New Hampshire, before entering the Merrimack River, as shown in Figure 37. The watershed area is 171 square miles. Wilton, Milford and Merrimack, minor industrial centers, are the major waste sources to the river. Their waste loads are listed in Table 3.

Time of travel studies were conducted on the Souhegan River from Wilton to the mouth. The resulting time of travel graph is shown in Figure 17. Appendix E summarizes the sanitary data obtained on the Souhegan River. Sampling station descriptions are given in the Appendix, page A-13.

Pollution from the Souhegan River communities upstream of Merrimack, New Hampshire, has a minor effect on the Merrimack River during the summer low flow period. Under conditions of cooler weather and higher river flows, the Souhegan River bacterial load may affect the Merrimack River. Severely polluted sections of the Souhegan River exist below Wilton and Milford. From a biological standpoint, the Souhegan River is moderately polluted from Wilton to the confluence with the Merrimack River[8].

The Souhegan River is presently used for bathing and fishing throughout most of its length. The coliform values observed are in



CHLORIDES IN MERRIMACK RIVER

AUGUST 25-28, 1964

FIGURE 36

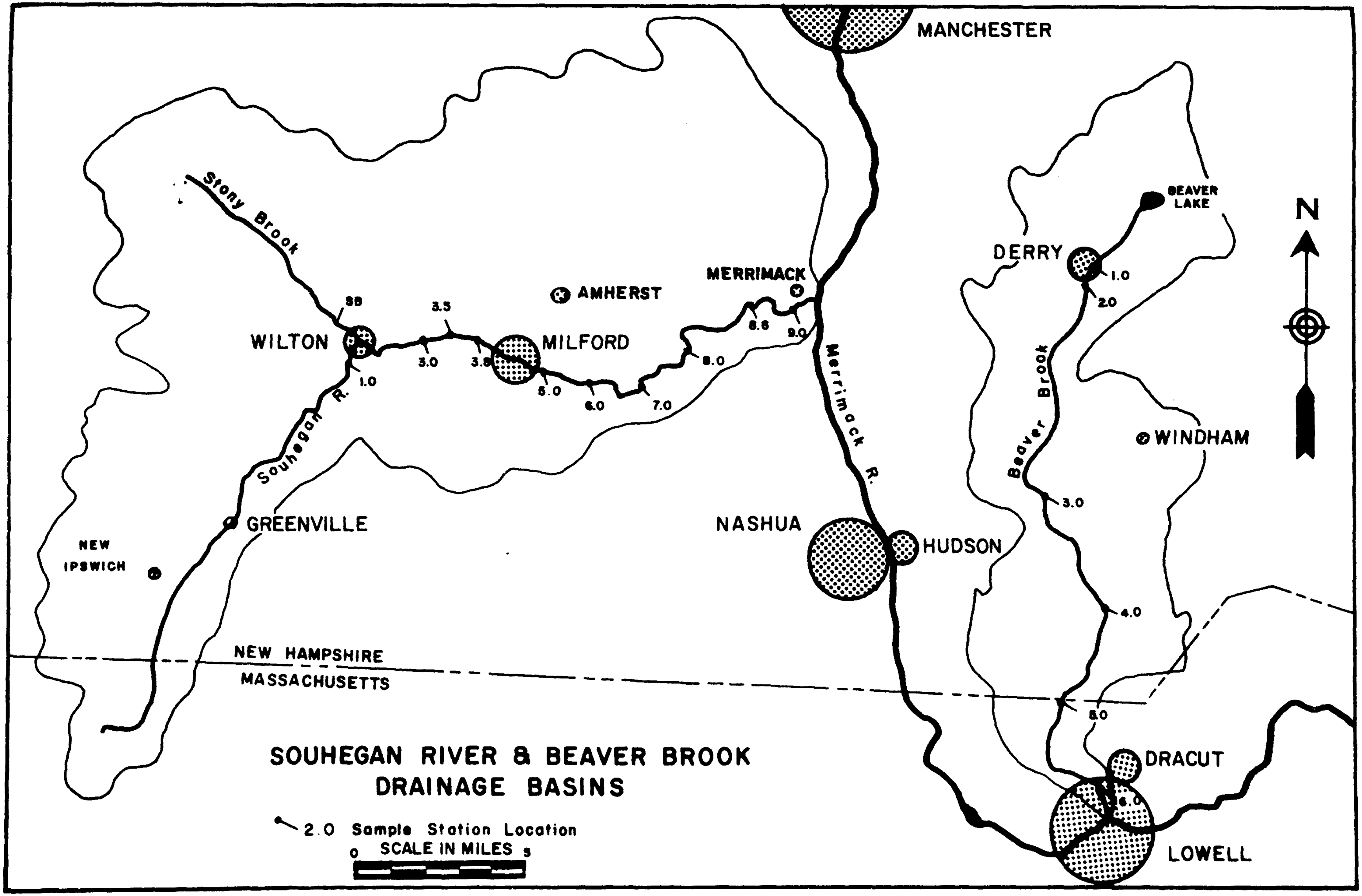

MANCHESTER
Stony Brook
BEAVER LAKE
N
DERRY
1.0
MERRIMACK
AMHERST
2.0
3B
3.5
8.6
9.0
WILTON
MILFORD
3.0
3.8
8.0
1.0
5.0
6.0
7.0
Merrimack R.
Beaver Brook
WINDHAM
Souhegan R.
3.0
GREENVILLE
NASHUA
HUDSON
NEW IPSWICH
4.0
NEW HAMPSHIRE
MASSACHUSETTS
5.0
DRACUT
6.0
LOWELL
SOUHEGAN RIVER & BEAVER BROOK DRAINAGE BASINS
2.0 Sample Station Location
SCALE IN MILES
0
5

FIGURE 37

excess of recommended bathing standards. At river mile 8.1, the city of Nashua has installed a pumping station in order to use the Souhegan River as a water supply.

The state of New Hampshire has adopted a limit of 1,000 coliforms per 100 ml for drinking water that receives treatment. However, the average coliform value of 12,800 found at that point (Station So-8.0) greatly exceeds this standard.

Nashua River

The Nashua River is the most severely polluted tributary of the Merrimack River. Appendix E summarizes the data obtained in order to evaluate the effect of Nashua River pollution on the Merrimack River. Part V of this report[20] discusses the Nashua River more completely. The Nashua River was very low in dissolved oxygen, high in BOD and indicative of bacterial pollution. A significant pollution load is contributed to the Merrimack River by discharges to the Nashua River, upstream of the city of Nashua, New Hampshire.

Beaver Brook

Beaver Brook begins at the outlet of Beaver Lake in Derry, New Hampshire, and flows south for about 25 miles to join the Merrimack River at Lowell, Massachusetts (Figure 37). The watershed area is 114 square miles; and the basin has a very high recreational usage.

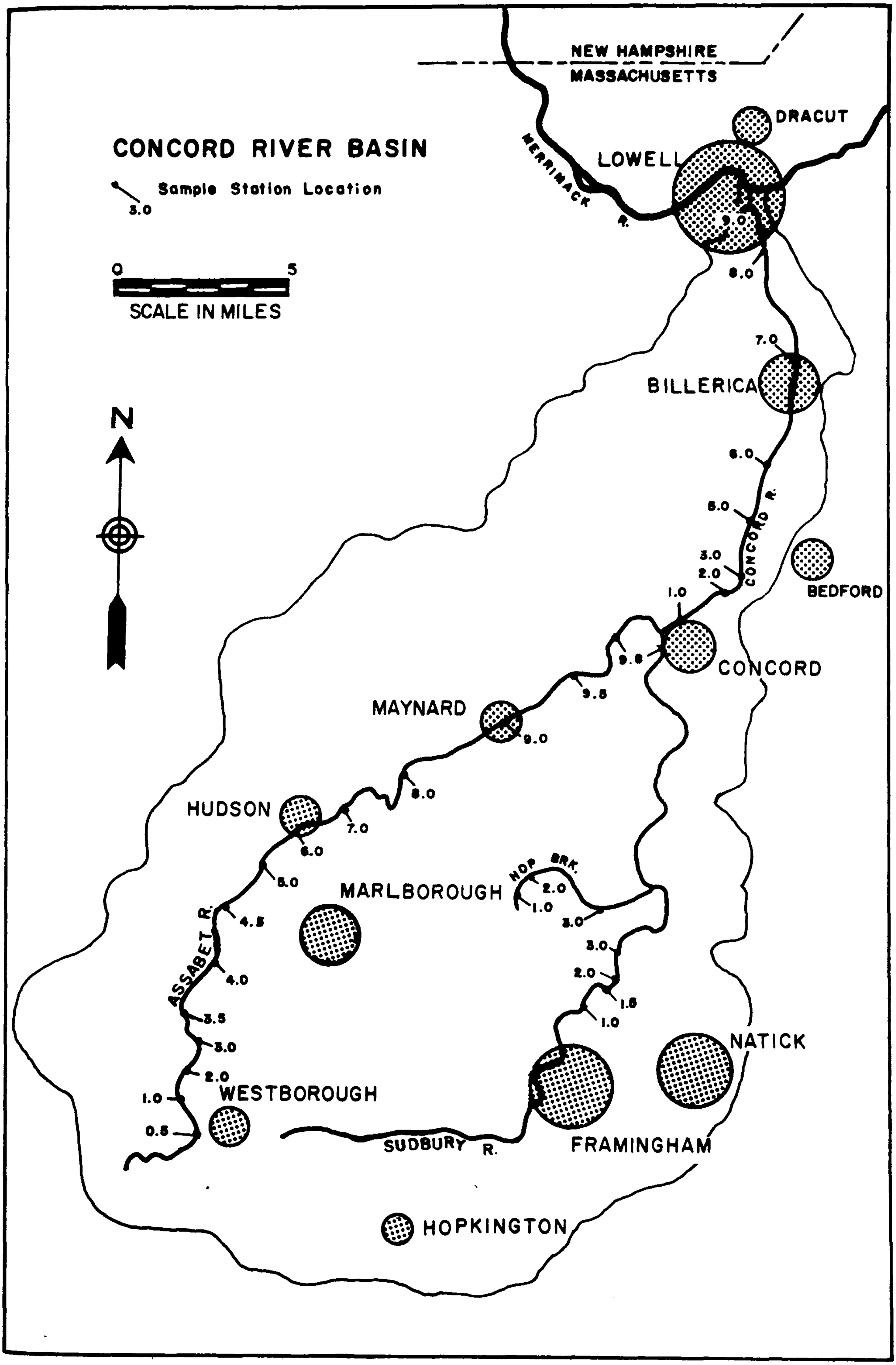
The low dissolved oxygen concentrations and high coliform values indicate that the brook is still polluted even after the newly constructed sewage lagoon at Derry, New Hampshire. High phosphate and coliform values near the mouth of Beaver Brook were caused by sewage discharges within Massachusetts. A summary of the data is given in Appendix E.

Concord River Basin

The Concord River has a watershed of 407 square miles and lies entirely within Massachusetts (Figure 38). The Sudbury River, with a drainage area of 163 square miles, originates in Westborough, Massachusetts. It flows easterly to Framingham, and then northerly to Concord, where it meets the Assabet River, forming the Concord River. The Assabet River also rises in Westborough, flows northerly to Hudson and then northeasterly to Concord, draining an area of 177 square miles. The Concord River flows northerly to the Merrimack River at Lowell, and drains an additional 67 square miles.

The Assabet River is severely polluted below Westborough. The remaining portion of the river is indicative of moderate pollution with noticeable reductions in stream quality below Hudson and Maynard.

High bacteria and BOD values were found near the Saxonville area of Framingham, on the Sudbury River. A tributary to the Sudbury, Hop Brook, in the vicinity of the historic Wayside Inn, was the most polluted tributary sampled in the Concord River watershed. Coliform values in excess of one million per 100 ml, dissolved oxygen values of 0.6 mg/l, BOD values of 40.0 mg/l and total phosphate values of 30 mg/l were found. Hop Brook receives the discharge from the Marlborough



CONCORD RIVER BASIN
Sample Station Location
3.0
0
5
SCALE IN MILES
N
NEW HAMPSHIRE
MASSACHUSETTS
DRACUT
LOWELL
MERRIMACK R.
BILLERICA
CONCORD R.
BEDFORD
CONCORD
MAYNARD
HUDSON
MARLBOROUGH
HOP BRK.
ASSABET R.
WESTBOROUGH
SUDBURY R.
FRAMINGHAM
NATICK
HOPKINGTON

FIGURE 38

sewage treatment plant.

Except for high phosphate concentrations, the Concord River was relatively unpolluted until it reached Billerica, where sewage and industrial wastes increased the coliform values and severely depressed the dissolved oxygen. When the Concord River reaches the Merrimack it has a significant impact on the Merrimack River water quality, due to the increased coliform values and depressed oxygen content of the water. The high content of nutrients in the Concord River results in growths of aquatic vegetation which may be a nuisance at times and cause taste and odor problems in the Billerica water supply.

Spicket River

The Spicket River originates in Island Pond in Salem, New Hampshire, and flows southerly to the New Hampshire-Massachusetts state line. Here it is joined by Policy Brook and flows southeasterly through Lawrence, Massachusetts, to the Merrimack River, as shown in Figure 39.

Excessive coliform densities were found in the New Hampshire portion of the river. As additional sewer outfalls are picked up by the new Salem, New Hampshire, sewage treatment plant, these densities should be reduced. Policy Brook had dissolved oxygen values at or near zero, and high BOD total phosphate and coliform values. This condition is due to raw discharges not yet connected to the treatment plant. Below the state line in Methuen, Massachusetts, the river has very high bacteria, phosphate and BOD values, while the dissolved oxygen is very low. This station includes wastes from Massachusetts discharges. Water quality data of the Spicket River are summarized in Appendix E.

Shawsheen River

Originating in Bedford, Massachusetts, the Shawsheen River flows northeasterly to meet the Merrimack River in Lawrence (Figure 39). The river is moderately polluted below Bedford and becomes more severely polluted with waste discharges as it flows through Andover. Laboratory data are summarized in Appendix E.

Little River

The Little River originates in Plaistow, New Hampshire, and flows in a general southerly direction until it meets the Merrimack River in Haverhill, Massachusetts. Only one area appeared to be seriously polluted, that being just above the state line where the total coliforms increased from 2,250 to 78,600 per 100 ml. The Little River Basin is shown in Figure 39; the data collected are given in Appendix E.

Powwow River

As shown in Figure 39, the Powwow River originates in Kingston, New Hampshire, and flows southeasterly to Amesbury, Massachusetts, where it meets the Merrimack River. The Town of Amesbury, Massachusetts, appears to be the only significant source of waste to the river. Sampling data are given in Appendix E.

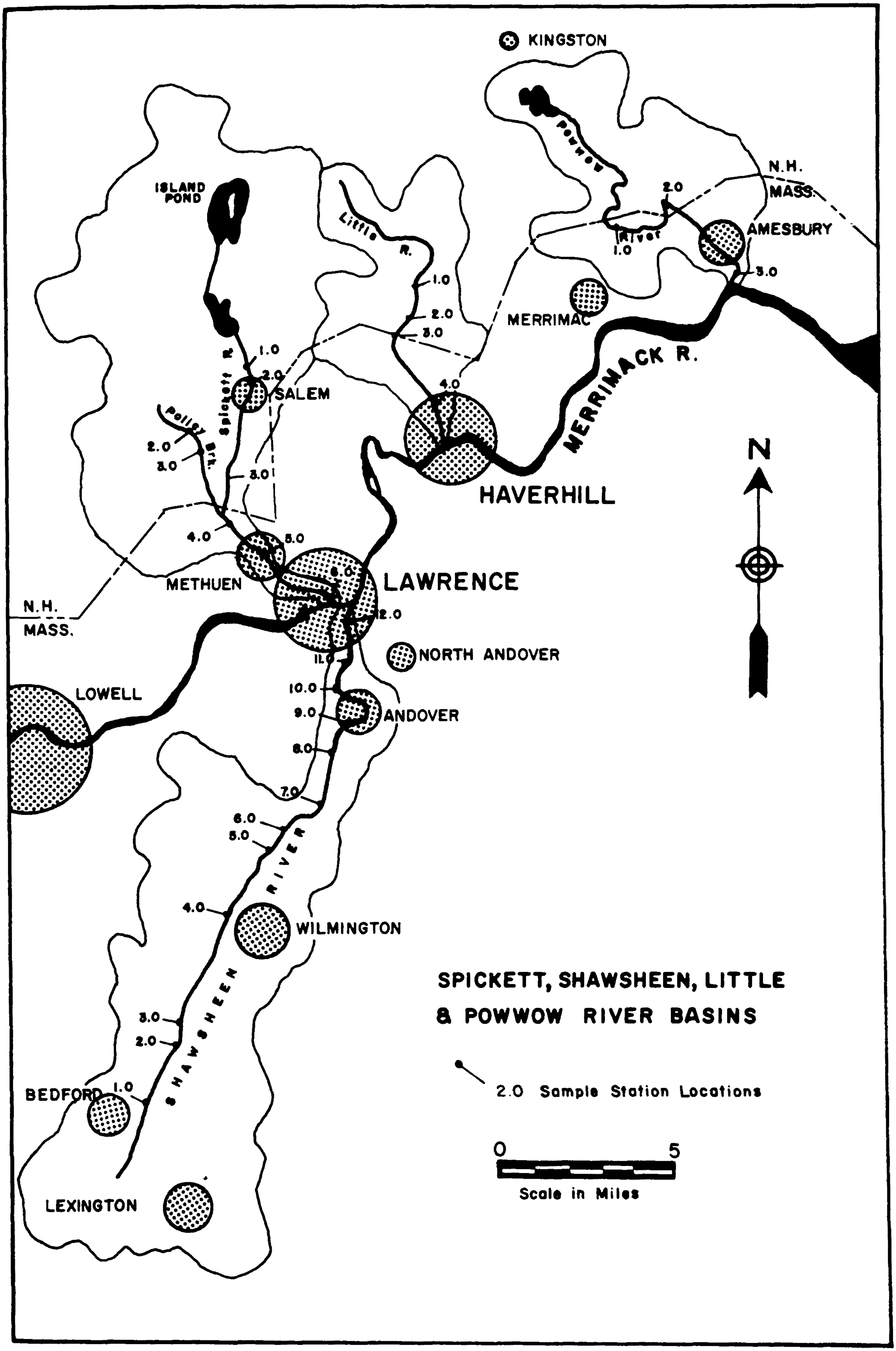

KINGSTON
ISLAND POND
Powwow
River
Little R.
Spickett R.
Pollet Brk.
SALEM
MERRIMAC
AMESBURY
N.H.
MASS.
MERRIMACK R.
HAVERHILL
N
METHUEN
LAWRENCE
N.H.
MASS.
NORTH ANDOVER
LOWELL
ANDOVER
SHAWSHEEN RIVER
WILMINGTON
BEDFORD
LEXINGTON
SPICKETT, SHAWSHEEN, LITTLE
& POWWOW RIVER BASINS
2.0 Sample Station Locations
0
5
Scale in Miles

FIGURE 39

Other Tributaries

Coliform samples were measured at several other tributaries at various times during 1964 and 1965. These included the Contoocook, Piscataquog, Soucook and Suncook. The sample data and station locations are given in Appendix E. The bacterial data indicated that none of the rivers appeared to have a significant affect on the Merrimack River.

OXYGEN BY PHOTOSYNTHESIS

In calculating the oxygen profiles for the Merrimack River, an expanded form of the Streeter-Phelps[21] equations was used. The equations include the addition of BOD by bottom deposits, removal of BOD by settling, and the production of dissolved oxygen by photosynthesis. The equations used in this report were developed by Camp[22], but Dobbins[23] has developed equations in approximately the same form.

The rate of production of dissolved oxygen by photosynthesis is designated alpha, $\underline{a}$, and was evaluated by the use of the light and dark bottle technique. The measurements are carried out in the euphotic zone, which is delimited by the vertical range of light effective in photosynthesis. Many factors, such as color, turbidity and the absorptive effect of water itself serve to quench light, thus, essentially determining the euphotic zone. The Merrimack River has a euphotic zone of about seven feet.

The loss of oxygen in the dark bottle represents planktonic respiration and oxygen used for bacterial metabolism. The change in oxygen concentration in the light bottle represents the net result of photosynthesis, respiration and bacterial metabolism (BOD). Therefore, the gross production of oxygen by algae is equal to the algebraic difference between the final light and dark bottle oxygen concentrations.

These studies were carried out concurrently with the intensive summer sampling periods at nine locations in the Merrimack River from

Manchester, New Hampshire, to below Haverhill, Massachusetts. Values were obtained at three depths at each location. The data obtained were plotted as oxygen production per day versus depth in the river (see Figure 40 for an example), resulting in a parabolic curve very closely resembling those of Hull[24]. To obtain an alpha value, a in ppm per day, for each reach, the area over the curve was divided by the hydraulic depth of the reach.

The alpha value on cloudy days was found to be much lower than the alpha for sunny days. Records from the U. S. Weather Bureau indicate that the sun was shining only 60 per cent of the time during the sampling period in 1964. During the summer of 1965, a recording pyrheliometer was used at Lawrence, Massachusetts, to measure sunlight intensity. In turn, this was graphically related to gross photosynthetic oxygen production (see Figures 41 and 42).

The resulting alpha values are summarized in Table 16.

TABLE 16

OBSERVED ALPHA VALUES FOR THE MERRIMACK RIVER
AUGUST 1964 - 65

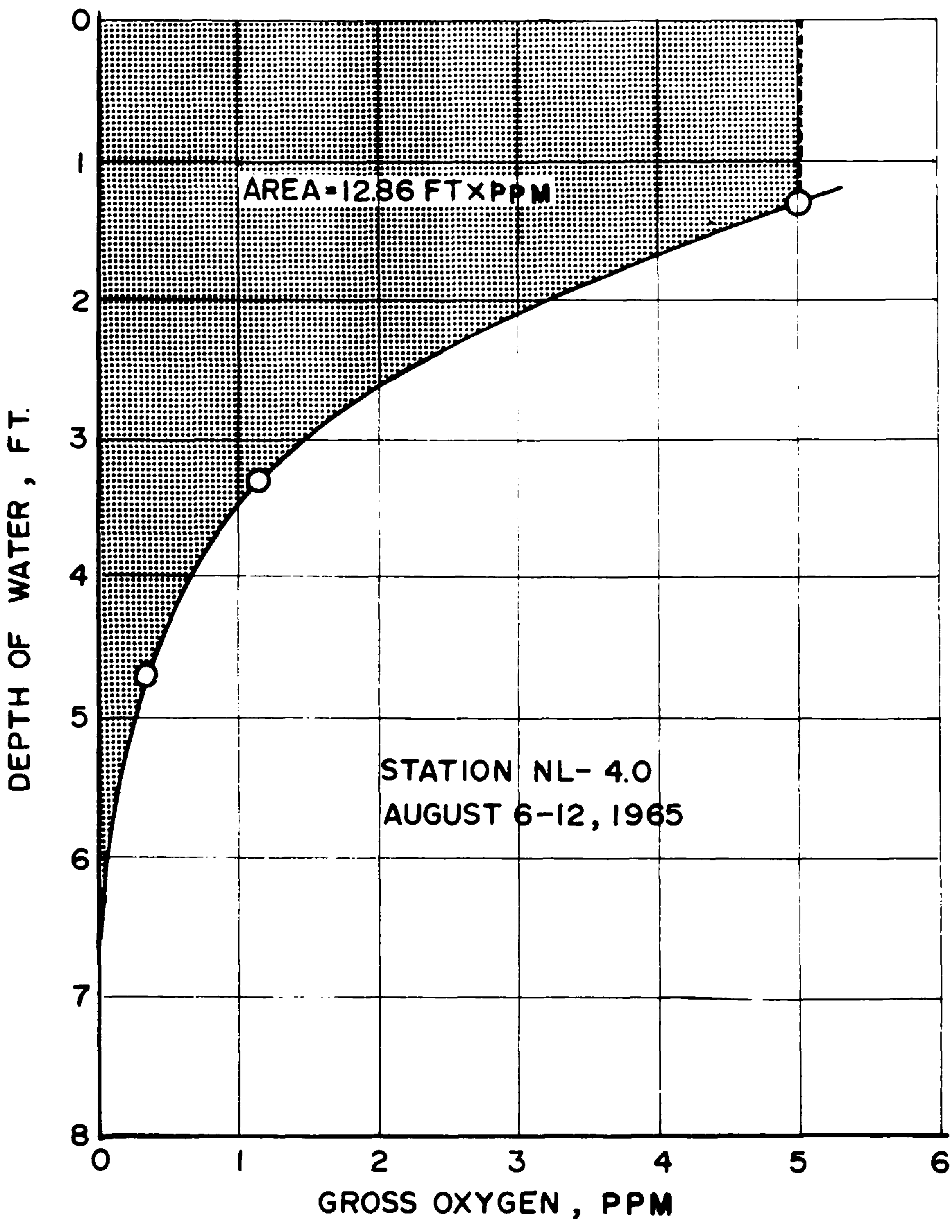
REACH	ALPHA, ppm/day
Manchester to Nashua, 1965	2.0
Nashua to Lowell, 1965	1.7
Nashua to Lowell, 1964	2.0
Lowell to Lawrence, 1964	0.8
Lawrence to Haverhill, 1964	1.0
Haverhill to Newburyport, 1964	1.7

SLUDGE DEPOSITS

In order to estimate the amount of solid material that has settled in the Merrimack River and its effect on the oxygen resources of the river, samples of these benthic deposits were obtained at numerous locations from Manchester, New Hampshire, to Newburyport, Massachusetts. These samples were analyzed for per cent moisture, total and volatile solids and specific gravity. The oxygen demand of this material was determined by both the Winkler BOD method and the Warburg procedure. From physical measurement of the river and laboratory analyses of the sludge, it was possible to calculate the oxygen demand of the benthal deposits, or "p", in ppm per day.

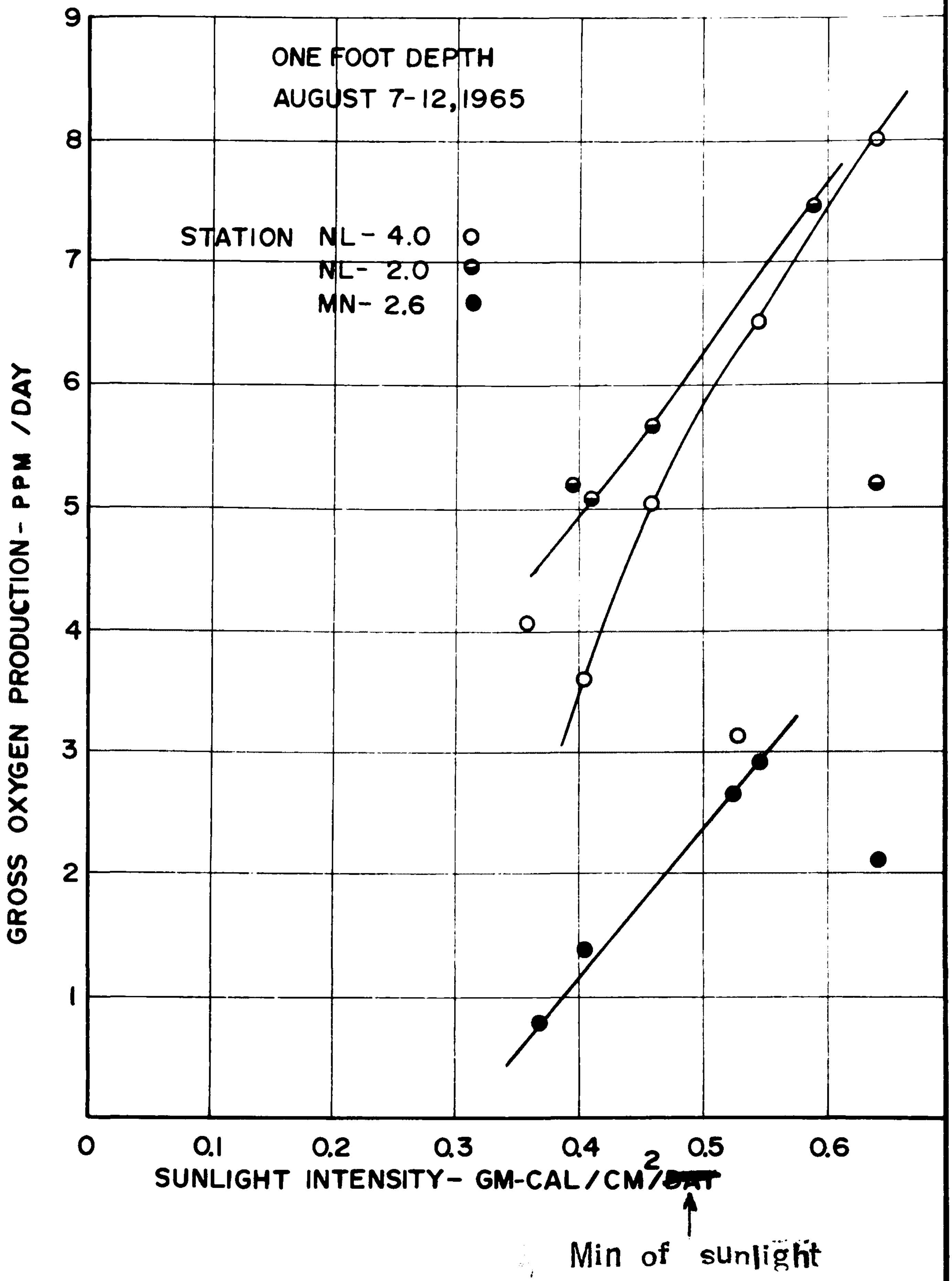
The average depth, area and volume of sludge in the Merrimack River during 1964 and 1965 are given in Table 17. If all the sludge in the river between Manchester and Newburyport were evenly distributed along the river bed, it would be slightly more than 3/8 of an inch deep.

In addition, a plant study was carried out that determined the oxygen demand under conditions similar to those encountered in the stream[25], and a value for the term p was calculated by using the results of this study. A representative value of p was selected for each reach based upon the two methods. Selection was influenced by field observations of the area, and the relationship of p with the observed oxygen sag calculations. A summary of the selected p values for each reach is given in Table 18.



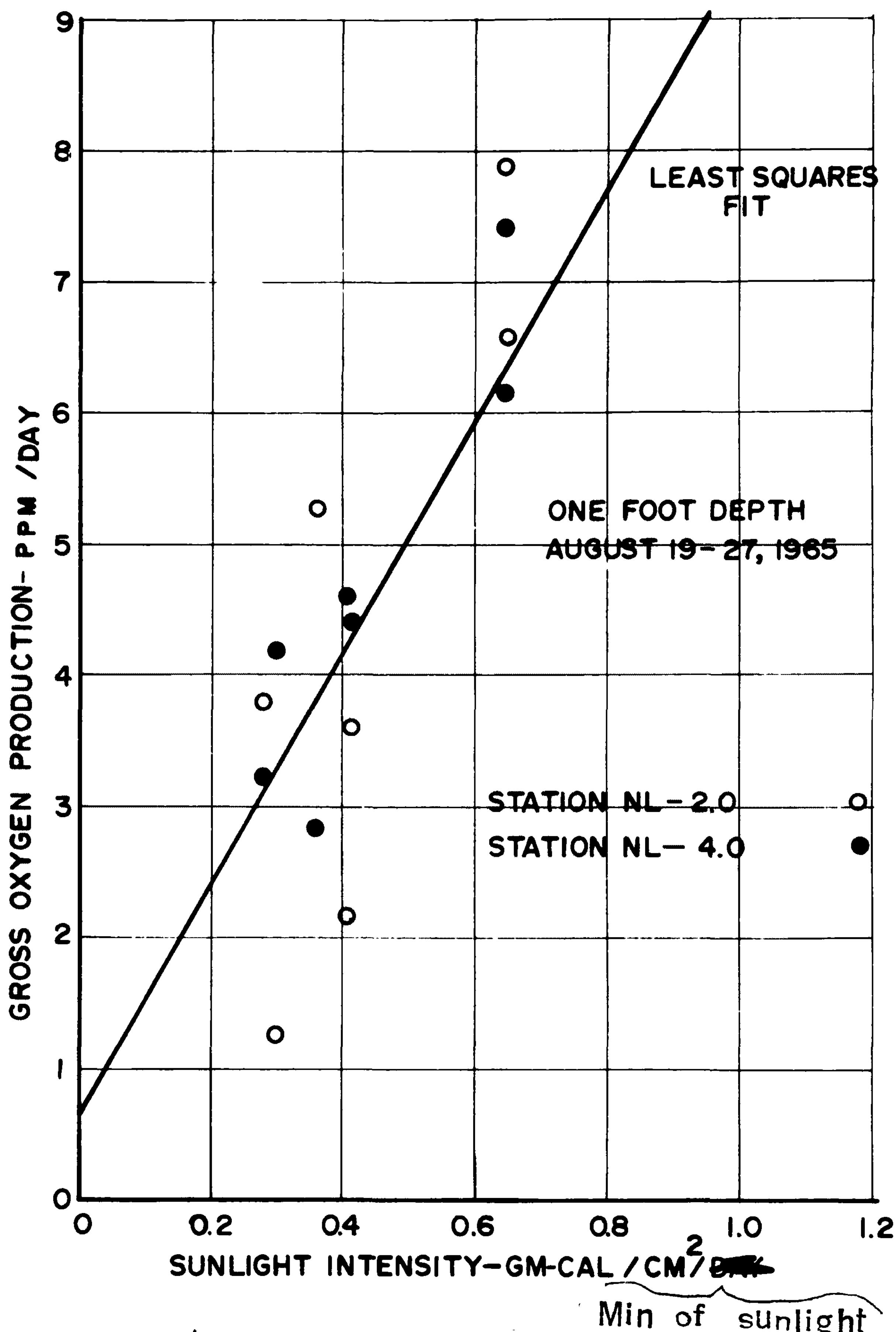
GROSS OXYGEN PRODUCTION VS. DEPTH

FIGURE 40



GROSS OXYGEN PRODUCTION VS. SUNLIGHT INTENSITY

FIGURE 41



GROSS OXYGEN PRODUCTION VS. SUNLIGHT INTENSITY

FIGURE 42

TABLE 17

AVERAGE DEPTH, AREA AND VOLUME OF MERRIMACK RIVER BENTHAL DEPOSITS

LOCATION	AVERAGE SLUDGE DEPTH (ft.)	SLUDGE AREA (ft^2)	SLUDGE VOLUME (ft^3)
Manchester to Nashua	0.021	38,600,000	800,000
Nashua to Lowell	0.021	18,000,000	400,000
Lowell to Lawrence	0.251	31,300,000	7,900,000
Lawrence to Haverhill	0.029	35,500,000	1,000,000
Haverhill to Newburyport	0.022	347,600,000	7,800,000
TOTAL	0.036	471,000,000	16,900,000

TABLE 18

OBSERVED p VALUES IN THE MERRIMACK RIVER AUGUST 1964-65

REACH	p, ppm/day
Manchester to Nashua, 1965	0.5
Nashua to Lowell, 1965	0.5
Nashua to Lowell, 1964	1.0
Lowell to Lawrence, 1964	0.5
Lawrence to Haverhill, 1964	0.2
Haverhill to Newburyport, 1964	0.9

OXYGEN BALANCE STUDIES

When organic material is deposited into a body of water, a natural process of decomposition begins. Bacteria begin to attack and alter the material; during this alteration dissolved oxygen is consumed. Often, this will result in a noticeable decrease in the dissolved oxygen content in a stream below a source of waste, followed by an increasing oxygen concentration still farther downstream. This is commonly called the "oxygen sag." By obtaining dissolved oxygen samples at various points downstream from a waste source, the oxygen sag curve may be drawn. Several methods are available to mathematically describe this curve. These methods are based upon adding the sources of oxygen (reaeration and photosynthesis) and subtracting the uses of oxygen (biochemical oxygen demand, sludge deposits, etc.) with respect to time. Once the mathematical model is solved and the river parameters are known for existing conditions, certain parameters can be altered to reflect a new set of conditions, such as increased waste loads or the installation of sewage treatment plants, and a new oxygen sag curve can be calculated to reflect these new conditions.

Concentrated studies described earlier were conducted in August 1964 and July-August 1965 from Concord, New Hampshire, to Newburyport, Massachusetts. During these studies data were obtained to enable the evaluation of all river parameters during the same time period.

DISCUSSION OF EQUATIONS

Two oxygen sag equations were used in calculating the Merrimack River parameters. The equation that was used most often was the "Camp equation"[22] which states:

$$D_b = \frac{k_1}{k_2-k_1-k_3}\left[L_a - \frac{p}{2.3(k_1+k_3)}\right]\left[10^{-(k_1+k_3)t} - 10^{-k_2t}\right]$$

$$+ \frac{k_1}{k_2}\left[\frac{p}{2.3(k_1+k_3)} - \frac{a}{2.3k_1}\right](1-10^{-k_2t}) + (D_a)\,10^{-k_2t} \qquad (1)$$

where

D_b = the oxygen deficit at some downstream station b in ppm,

D_a = the oxygen deficit at some upstream station a in ppm,

L_a = the ultimate BOD load at station a in ppm,

p = the rate of addition of BOD to the overlying water from the bottom deposits in ppm per day,

a = the gross production of oxygen by photosynthesis in ppm per day,

k_1 = the deoxygenation constant per day,

k_2 = the atmospheric reaeration constant per day,

k_3 = the rate of settling out of BOD to the bottom deposits per day.

The BOD reduction equation using Camp's approach is

$$L_b = \left[L_a - \frac{p}{2.3(k_1+k_3)}\right] 10^{-(k_1+k_3)t} + \frac{p}{2.3(k_1+k_3)}\,. \qquad (2)$$

The Camp equation is basically the same as the familiar Streeter-Phelps equation:

$$D_b = \frac{k_1}{k_2-k_1} \quad L_a \left[10^{-k_1t} \quad -10^{-k_2t}\right] + (Da)\ 10^{-k_2t} \tag{3}$$

when k_3, a, and p are negligible. The BOD reduction equation is then given:

$$L_b = (L_a)\ 10^{-k_2t} \quad . \tag{4}$$

The Streeter-Phelps equation[21] was used to determine the river parameters in three reaches from Concord to Nashua, New Hampshire. In order to compare results obtained in 1964 and 1965 to those used in the design of proposed pollution control works, the Camp equations were used for the reaches from Manchester, New Hampshire, to Newburyport, Massachusetts. The reach from Manchester, New Hampshire, to Nashua New Hampshire, was calculated by both the Streeter-Phelps and Camp equations for the purpose of comparing the river parameters.

PROCEDURE

In evaluating the parameters in the equations, the basic objective was to duplicate mathematically the results obtained by detailed stream sampling of the Merrimack River. Gross photosynthetic oxygen production, alpha, was determined as described in the section on oxygen by photosynthesis. A summary of the a values used in calculation for each reach is given in Table 16. The rate of addition of BOD to the overlying water, p, was determined by measuring the oxygen demand of the benthal deposits in the Merrimack River, as described in the section on sludge deposits. Table 17 lists the selected p values for the various reaches. Time of stream travel for the various reaches and intermediate points of the river was determined at various flows, as described in the section on time of stream travel. Table 19 summarizes the time of travel for the period of intensive sampling.

TABLE 19

TIME OF TRAVEL FOR SURVEY PERIOD

YEAR	REACH	RIVER MILES FROM	TO	AVG FLOW CFS	TIME DAYS	VELOCITY MILES/DAY
1965	CH	90.23	80.60	650	3.05	3.16
1965	HM	80.60	73.14	680	3.84	1.94
1965	MN	71.07	54.55	770	2.32	7.12
1965	NL	54.55	43.47	770	2.43	4.56
1964	NL	54.55	43.47	1125	1.90	5.83
1964	LL	37.45	28.99	1200	2.73	3.10
1964	LH	26.45	18.85	2200	0.89	8.94
1964	HN	18.85	2.94	2200	4.20	3.79

*CH = Concord to Hooksett, HM = Hooksett to Manchester, MN = Manchester to Nashua, NL = Nashua to Lowell, LL = Lowell to Lawrence, LH = Lawrence to Haverhill and HN = Haverhill to Newburyport.

Using the deoxygenation constant, the BOD_5 value found was converted to the ultimate BOD value, L, and the loadings from major pollution sources were calculated using population and industrial loading data from consulting engineer reports. The rate of BOD settling out, k_3, was then determined by solving equation 2. Initial and final oxygen deficits, D_a and D_b, were determined from stream data, and k_2 was calculated from equation 1, resulting in a k_2 that was generally negative or of very low positive value. Considering the low dissolved oxygen levels and physical characteristics of the Merrimack River, such k_2 results were not considered representative. Consequently, an analysis was made of the various parameters to determine whether or not any were in error. By stochastically selecting values for the variables over a wide range and solving the equations by trial-and-error, an oxygen sag curve was obtained that conformed to the observed field data.

Consideration was first made of a. By selecting values for a as low as zero, it was determined that although a contributed a significant portion of the oxygen added to the river during the field survey, this portion was not enough to mathematically yield negative k_2 values. In addition, the a values found on the Merrimack River were comparable to those found by others [2].

The benthal effect was considered next. It was found that by increasing p to values between 10 and 50 ppm/day, a positive k_2 could be obtained. Such values of p were not probable, however. Evaluation of the bottle deoxygenation constant, k_1, was made from long term BOD data. BOD determinations were made at 2, 3, 4, 5, 7 and 10 day intervals, and the results were calculated by one or more of the following methods: graphical fitting of curve[26], method of moments[27], daily difference[28], and rapid ratio method[29].

When more than one method was used, as was common, the results were compared and a representative value was selected. Table 20 shows the selected bottle k_1 values found during August of 1964 and 1965 for the selected river reaches.

TABLE 20

BOTTLE DEOXYGENATION CONSTANTS

REACH	YEAR	k_1 per day
CH	1965	0.05
HM	1965	0.05
MN	1965	0.09
NL	1965	0.04
NL	1964	0.03
LL	1964	0.045
LH	1964	0.05
HN	1964	0.07

It was found that by increasing the quantity (k_1+k_2), or the effective BOD removal term, reasonable k_2 values which used the previously observed $\underline{a}$ and p values could be obtained. By leaving k_1 equal to that found by long term BOD analysis and increasing only

k_3, reasonable values of k_2 were obtained with k_3 values in the range of 0.1 to 1.0 per day. A k_3 value in this range would result in a ratio of k_3 to k_1 of twenty or more and should yield tremendous sludge deposits in the river. Since these great sludge areas were not in evidence even after several years of drought conditions, it was obvious that the "bottle k_1" values of 0.03 and 0.07 were not representative of the "river k_1", and that a new approach was required.

In the revised method of analysis, the a and p values that were previously determined were considered valid and were used in the calculations. The bottle k_1 values were used to compute initial ultimate BOD loadings from waste sources and to compute river ultimate BOD, L, values from the 5-day BOD values. Using a plot of L versus time of flow, a combined (k_1+k_3) term was calculated. Since any number could be selected for k_1, and then a k_3 determined from $(k_1+k_3 = C)$, the respective values of k_1 and k_3 could not be analyzed without using equation 1. By means of trial-and-error analysis and the previously determined a and p, it was possible to determine values for k_1, k_3 and k_2 that would duplicate the observed field conditions. Although this method can produce more than one set of "reasonable" values for k_1, k_2 and k_3, none of the sets of such "reasonable" values produced any wide variations in the parameters. An example would be the set of parameters shown below.

VALUE OF			OXYGEN DEFICIT D AT TIME T =			
k_1	k_2	k_3	0.5 day	1.0 day	2.0 days	SUM OF DIFFERENCES
Field Data	—	—	3.97	3.91	2.90	—
0.140	0.110	0.200	4.00	3.98	2.96	0.16
0.140	0.120	0.200	4.01	3.96	2.93	0.09
0.140	0.130	0.200	4.02	3.91	2.82	0.13

In this example, the parameter selected would be k_3 = 0.120 per day, provided that the values of k_1 and k_2 had been similarly tested. As shown in the example, the quantity of k_1+k_3 was not kept constant, but was varied slightly to produce a better fitting curve. When the final k_1+k_3 total was used to recalculate equation 2, very little change was noticed.

The above discussion on solving the Camp equations also applies to the Streeter-Phelps equations 3 and 4, with two exceptions: a and p are included in k_2, and the k_1 is a combination of Camp's k_1+k_2. Of course, the fitting of the curve by trial-and-error is greatly simplified when there are only two unknowns.

Due to tidal action in the reach HN, special methods were employed. Data had to be collected as near low or high slack tides as possible. Values near low slack tide were averaged for use in the equations, as recommended by Camp for design purposes[22]. Equation 1 was modified to define:

$$D_b = \frac{k_1}{k_2-k_1-k_3}\left[L_a - \frac{p}{2.3(k_1+k_3)}\right]\left(10^{j_1 x} - 10^{j_2 x}\right)$$

$$+ \frac{k_1}{k_2}\left[\frac{p}{2.3(k_1+k_3)} - \frac{a}{2.3k_1}\right]\left(1-10^{j_2 x}\right) + (D_a)\,10^{j_2 x} \qquad (5)$$

and equation 2 was modified to define:

$$L_b = \left[L_a - \frac{p}{2.3(k_1+k_3)}\right] 10^{j_1 x} + \frac{p}{2.3(k_1+k_3)} \qquad (6)$$

where

$$j_1 = 0.434\left[\frac{U}{2e} - \sqrt{\frac{U^2}{4e^2} + \frac{2.3(k_1+k_3)}{e}}\right] \qquad (7)$$

$$j_2 = 0.434\left[\frac{U}{2e} - \sqrt{\frac{U^2}{4e^2} + \frac{2.3k_2}{e}}\right] \qquad (8)$$

where

x = distance from station a, miles,

U = temporal mean velocity of the flowing stream, miles/day,

e = turbulent transport coefficient, square miles/day, and is defined by the relationship:

$$S = S_o \cdot 10^{-0.434\frac{U}{e}x} \qquad (9)$$

where

S = the salinity or chloride concentration at mile x upstream from Station b,

S_o= the salinity or chloride concentration at the downstream Station b.

The average chloride values shown in Table 15 were used to calculate the turbulent transport coefficient. This coefficient was found to be about 5.0 square miles/day from equation 9. Over the entire reach from Haverhill to Newburyport, Massachusetts, U was found to be 3.79 miles/day.

By means of trial-and-error procedures and the previously determined values for a, p, e and U, it was possible to determine values for k_1, k_3 and k_2 that would duplicate the observed field conditions.

Table 21 summarizes the values found for all parameters, and Figure 43 compares the calculated oxygen sag curves to the observed data.

DISCUSSION OF OXYGEN SAG CURVES

Average dissolved oxygen values obtained during the intensive field surveys and the oxygen sag curves obtained from parameters based on the field data are shown in Figure 43. In most reaches a good correlation between observed and calculated data was found. Typical oxygen sag curves are found below Concord, Hooksett-Allenstown-Pembroke, Manchester, Nashua, Lowell and Haverhill.

TABLE 21

SUMMARY OF RIVER PARAMETERS

AUGUST 1964-1965

REACH	RIVER MILES	YEAR	FLOW CFS	TIME DAYS	TEMP °C	BOTTLE k_1 PER DAY	L_a PPM	D_a PPM	METHOD	k_1 PER DAY	k_2 PER DAY	k_3 PER DAY	a PPM PER DAY	p PPM PER DAY
CH	90.23 to 80.60	1965	650	3.05	23 & 24	0.05	5.16	3.48	Streeter -Phelps	0.220	0.270	--	--	--
HM	80.60 to 73.14	1965	670	3.84	24	0.05	4.12	2.33	Streeter -Phelps	0.115	0.105	--	--	--
MN	71.07 to 54.55	1965	770	2.32	24	0.09	10.01	4.88	Streeter -Phelps	0.300	0.400	--	--	--
									Camp	0.260	0.190	0.040	2.00	0.50
NL	54.55 to 43.47	1965	770	2.43	24	0.04	16.25	3.53	Camp	0.130	0.210	0.140	1.70	0.50
		1964	1125	1.90	22	0.03	21.82	3.77	Camp	0.095	0.230	0.040	2.00	1.00
LL	37.45 to 28.99	1964	1200	2.73	22	0.045	13.72	5.67	Camp	0.161	0.160	0.010	0.80	0.50
LH	26.45 to 18.85	1964	2200	0.89	22	0.05	18.53	5.87	Camp	0.175	0.220	0.010	1.00	0.20
HN	18.85 to 2.94	1964	2200	4.20	21	0.07	18.11	7.08	Camp	0.175	0.140	0.000	1.70	0.90

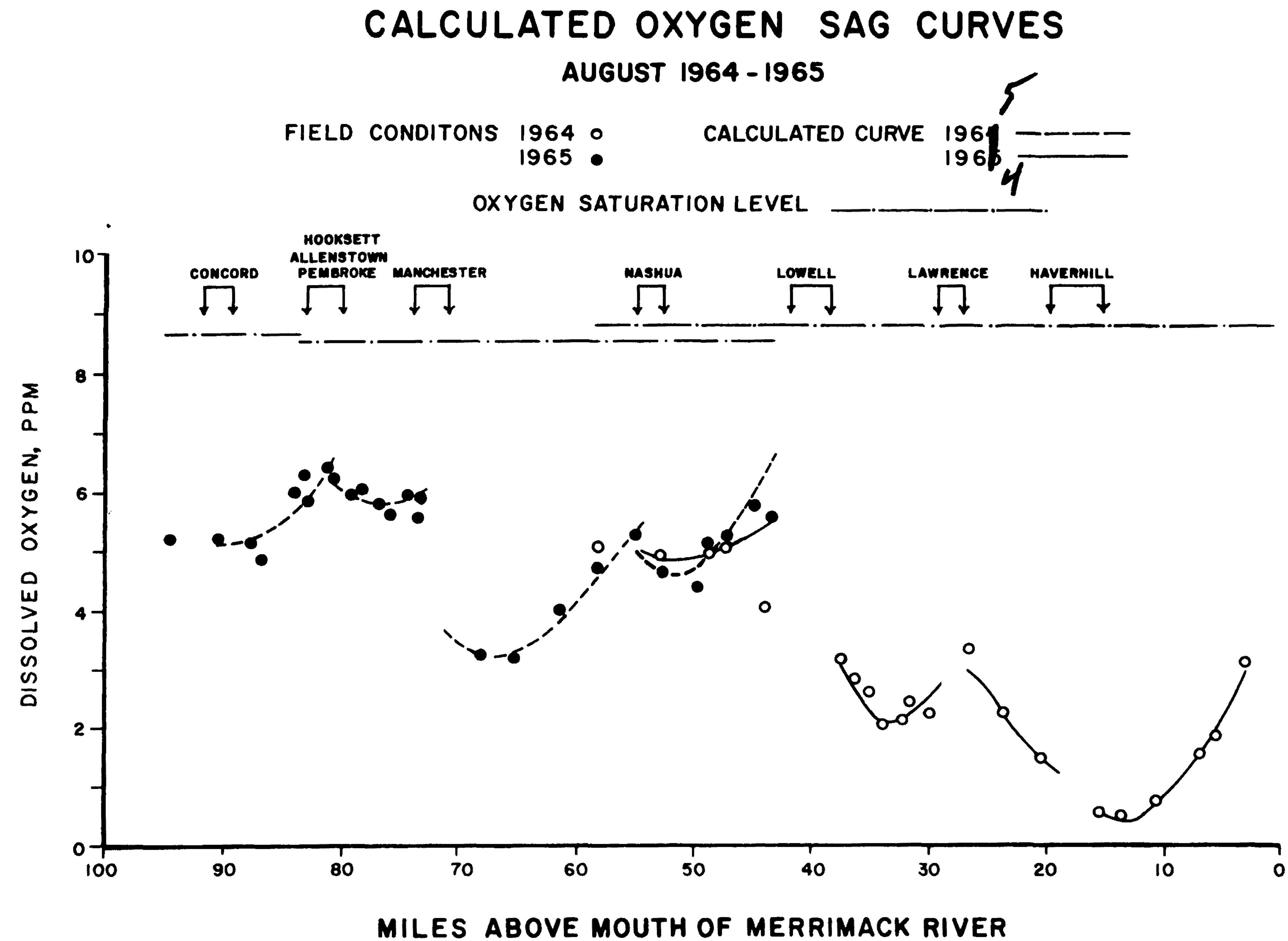

CALCULATED OXYGEN SAG CURVES
AUGUST 1964 - 1965
FIELD CONDITONS 1964
1965
CALCULATED CURVE 1964
1965
OXYGEN SATURATION LEVEL
CONCORD
HOOKSETT
ALLENSTOWN
PEMBROKE
MANCHESTER
NASHUA
LOWELL
LAWRENCE
HAVERHILL
DISSOLVED OXYGEN, PPM
MILES ABOVE MOUTH OF MERRIMACK RIVER
0
2
4
6
8
10
100
90
80
70
60
50
40
30
20
10
0

FIGURE 43

The Lawrence to Haverhill section of the Merrimack River was the only reach of the seven that did not reach the bottom of the sag before the next major waste load entered.

The oxygen sag curves presented in this section reflect only those conditions found during the intensive sampling periods of August 1964 and 1965. They do not reflect the lowest oxygen values ever observed in the Merrimack River nor do they reflect the lowest values found during the intensive survey. For example, at Station HN-6.0 at the Newburyport, Massachusetts, railroad bridge, the most seaward station, the average dissolved oxygen during the intensive period was 5.06 ppm, but the range was 1.7 to 8.4 ppm. Minimum values of zero were observed at two stations below Haverhill. Of course, these minimum values were far below the dissolved oxygen levels required for aquatic life and would have deleterious effects on these organisms. During the year, due to many varying natural events, the values of the parameters k_1, k_2, k_3, $\underline{a}$ and p can be expected to vary significantly. For example, values of $\underline{a}$ may be found that range from negative (algae respiration exceeding the photosynthetic production of oxygen) to positive values that can produce oxygen concentrations above saturation levels.

These parameters may be used to aid in predicting the oxygen balance relationships under altered conditions, provided that the values have been selected to reflect the environmental conditions.

INFLUENCE OF PARAMETER VARIATION

A detailed evaluation of the data between Manchester, New Hampshire, and Nashua, New Hampshire, was made to determine the significance of the terms k_3, a and p in the Camp equation. These three parameters were not in the Streeter-Phelps equation.

$$D_b = \frac{k_1}{k_2-k_1-k_3}\left[L_a - \frac{p}{2.3(k_1+k_3)}\right]\left[10^{-(k_1+k_3)t} - 10^{-k_2 t}\right]$$

$$+ \frac{k_1}{k_2}\left[\frac{p}{2.3(k_1+k_3)} - \frac{a}{2.3\, k_1}\right](1-10^{-k_2 t}) + (D_a)\, 10^{-k_2 t} \qquad (1)$$

Using the previously determined field condition parameters of

L_a = 10.01 ppm $\qquad$ D_a = 4.88 ppm

k_1 = 0.26 per day, k_2 = 0.19 per day, k_3 = 0.04 per day

a = 2.00 ppm per day $\qquad$ p = 0.5 ppm per day

evaluation was made by calculating D_b at selected times t under various conditions as stated below:

Condition 1. All parameters as given above,

2. k_3 = 0.00,

3. p = 0.00,

4. a = 0.00,

5. a = 0.00 and p = 0.00,

6. a = 0.00, p = 0.00 and k_3 = 0.00.

Two distinct groupings are evident in Figure 44. The first, conditions 1, 2 and 3, is that situation where a = 2.00 ppm per day; and the second, conditions 4, 5 and 6, is the situation where a has been reduced to 0.00 ppm per day. Conditions 2 and 6, where k_3 = 0.00 per day, show that a change of k_3 has only a minor effect on the oxygen sag curve. The same is true for p. The curves for conditions 3 and 5, where p = 0.00 ppm per day, are similar to the curves for conditions 1 and 4, respectively. Obviously, in this reach, as in the other reaches of the Merrimack River analyzed, the resulting field values of p and k_3 have a minor effect on the oxygen-sag equation given by Camp.

The photosynthetic production of oxygen, a, does have a highly significant effect. In the above example with t = 2.0 days and a = 2.00 ppm per day, the a accounts for an additional 2.67 ppm of dissolved oxygen. This represents 54 per cent of the DO value of 4.93.

RELATIONSHIP BETWEEN RIVER AND BOTTLE k_1

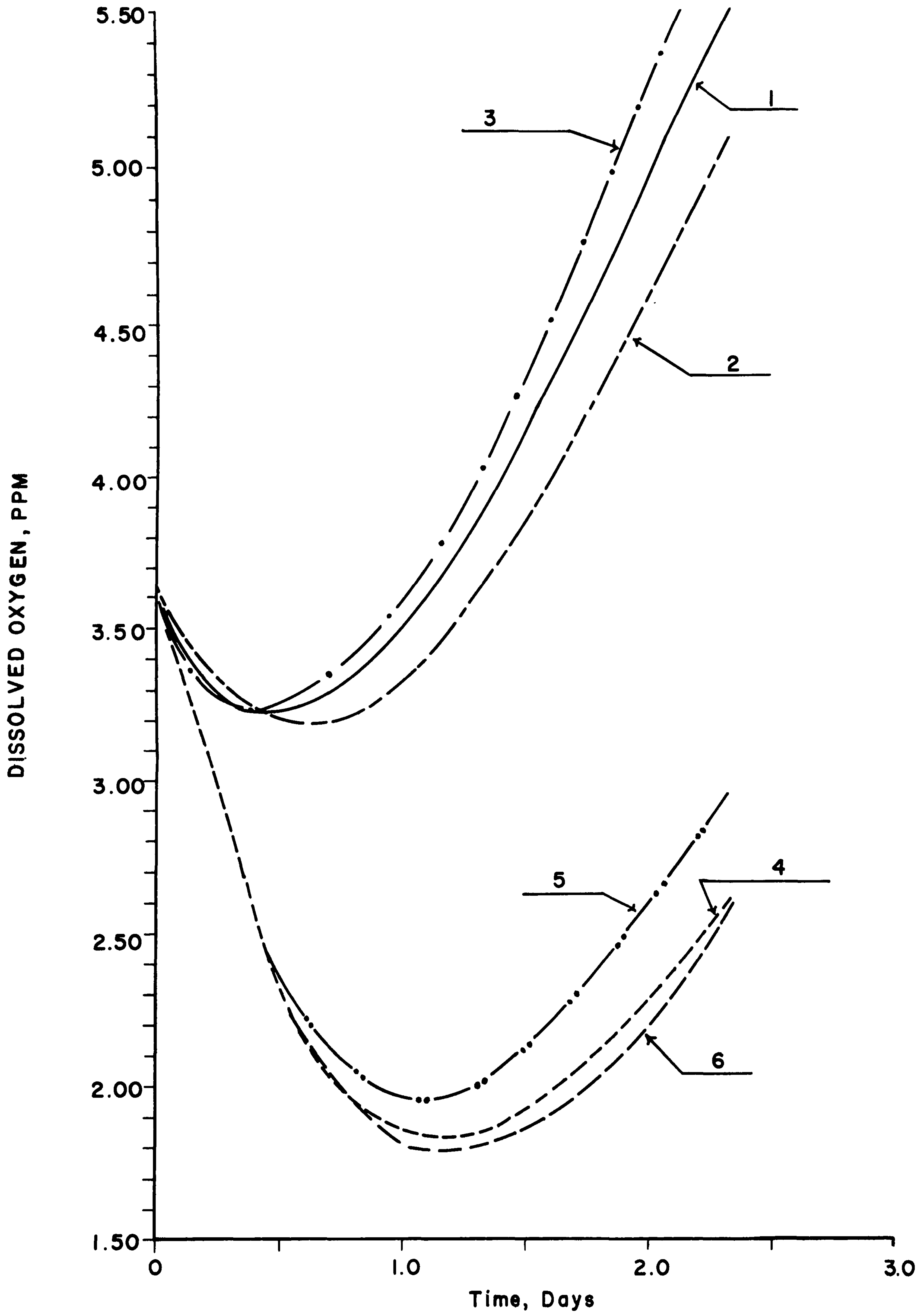
Since it was found that the rate of removal of BOD in the river was not equal to that occurring in the bottle, k_1 for the river was found by use of the Camp equation. A comparison of the river and bottle k_1's revealed that a relatively close ratio existed between the two. This is demonstrated in Table 22.

TABLE 22

RATIO OF BOTTLE AND RIVER DEOXYGENATION COEFFICIENTS

REACH	BOTTLE k_1	RIVER k_1	RATIO
MN	0.09	0.26	.35
NL (1965)	0.04	0.13	.31
NL (1964)	0.03	0.095	.32
LL	0.045	0.161	.28
LH	0.05	0.175	.29
HN	0.07	0.175	.40

An average of the six reaches indicates a ratio of bottle k_1 to river k_1 of 1:3. The decimal range is 0.12, and if the estuary reach HN is not considered, the range is only 0.07.



$$D_b = \frac{k_1}{k_2 - k_1 - k_3}\left[L_a - \frac{P}{2.3(k_1+k_3)}\right]\left[10^{-(k_1+k_3)t} - 10^{-k_2 t}\right] + \frac{k_1}{k_2}\left[\frac{P}{2.3(k_1+k_3)} - \frac{a}{2.3k_1}\right]\left(1 - 10^{-k_2 t}\right) + D_a \cdot 10^{-k_2 t}$$

FIELD CONDITIONS AUGUST, 1965

1	$k_1 = 0.26$, $k_2 = 0.19$, $k_3 = 0.04$, $\underline{a} = 2.0$, $p = 0.5$
2	$k_1 = 0.26$, $k_2 = 0.19$ $\underline{a} = 2.0$, $p = 0.5$
3	$k_1 = 0.26$, $k_2 = 0.19$, $k_3 = 0.04$, $\underline{a} = 2.0$
4	$k_1 = 0.26$, $k_2 = 0.19$, $k_3 = 0.04$ $p = 0.5$
5	$k_1 = 0.26$, $k_2 = 0.19$, $k_3 = 0.04$
6	$k_1 = 0.26$, $k_2 = 0.19$

INFLUENCE OF PARAMETER VARIATION

FIGURE 44

PROJECTED OXYGEN CONDITIONS

For convenience in design calculations, the river reaches used in 1964-65 field surveys were redefined as extending downstream from the point of discharge of one proposed sewage treatment plant to the next proposed discharge. Continuous calculations were then possible.

Since concentrated sampling was not conducted in the reaches from Franklin to Penacook, New Hampshire, reach FP, and from Penacook to Concord, New Hampshire, reach PC, no river parameters were calculated. However, the reaches were considered to be similar in nature and received a waste similar in composition to that found in reach CH. Parameters of reach CH were, therefore, adopted for reaches FP and PC.

The reference to the proposed Hooksett sewage treatment plant includes the combined discharges of separate treatment plants at Hooksett, Allenstown and Pembroke, New Hampshire, while the Concord sewage is discharged from two plants, one in Penacook and the other in Concord. All the other proposed treatment plants would receive sewage from the metropolitan areas of Manchester, Nashua, Lowell, Lawrence and Haverhill. The nine river reaches used in calculations are defined in Table 23.

General Design Parameters

Selection of design flows in the river reaches was based upon the 10 per cent occurrence of the average seven day August flow

TABLE 23

RIVER REACHES USED FOR PROJECTIONS

REACH	LOCATION	RIVER MILES	LENGTH, MILES	FLOW, CFS	TIME OF TRAVEL DAYS
	Franklin	115.70			
FP	to	to	15.39	595	2.40
	Penacook	100.31			
PC	to	to	11.18	720	1.05
	Concord	89.13			
CH	to	to	8.93	740	2.65
	Hooksett	80.20			
HM	to	to	11.67	760	3.70
	Manchester	68.53			
MN	to	to	15.20	830	2.20
	Nashua	53.33			
NL	to	to	16.59	950	3.15
	Lowell	36.74			
LL	to	to	11.18	1,000	3.26
	Lawrence	25.56			
LH	to	to	8.17	1,000	2.31
	Haverhill	17.39			
HN	to	to	14.45	1,000	6.59
	Newburyport	2.94			

in the Merrimack River and tributaries. The flow values selected for each reach are given in Table 23. Once the flows were selected, Figures 11 through 14 were referred to, and the time of stream travel for the appropriate river miles within each reach was determined. Table 23 summarizes the total time of flow for each reach.

The year 1985 was selected as the design year for the following reasons:

1. A twenty-year life expectancy of sewage treatment plant equipment.
2. Availability of reliable population growth predictions.
3. Ample time for the stabilization of conditions in the river following the changes produced by sewage treatment plants.

Design temperature values of 24°C above Concord, New Hampshire, and 25°C below were selected, based upon recorded field temperatures in August of 1964 and 1965.

Photosynthetic Oxygen Production and Benthal Demand

For design purposes, the $\underline{a}$ value, or photosynthetic oxygen production rate, was selected to reflect the minimum production that could be reasonably expected in August. The values selected are shown in Table 24 and reflect conditions on a dark cloudy day. Selection of such values was based on light-and-dark bottle studies of 1964 and 1965, using the observed cloudy day values. With large algae populations present, it would not be unreasonable to expect a negative

TABLE 24

SUMMARY OF RIVER DESIGN PARAMETERS

AUGUST 1985

REACH	RIVER MILES	FLOW CFS	TIME DAYS	TEMP °C	L_a PPM	D_a PPM	METHOD	k_1 PER DAY	k_2 PER DAY	k_3 PER DAY	a PPM PER DAY	p PPM PER DAY
FP	115.70 to 100.31	595	2.40	24	3.12	2.13	Streeter -Phelps	0.100	0.250	--	--	--
PC	100.31 to 89.13	720	1.05	24	2.96	1.33	Streeter -Phelps	0.100	0.250	--	--	--
CH	89.13 to 80.20	740	2.65	25	2.88	1.35	Streeter -Phelps	0.100	0.250	--	--	--
HM	80.20 to 68.53	760	3.70	25	2.14	0.92	Streeter -Phelps	0.090	0.100	--	--	--
MN	68.53 to 53.33	830	2.20	25	3.86	1.45	Camp	0.120	0.180	0.010	0.20	0.20
NL	53.33 to 36.74	950	3.15	25	3.57	1.80	Camp	0.080	0.170	0.010	0.20	0.30
LL	36.74 to 25.56	1,000	3.26	25	5.93	1.70	Camp	0.080	0.170	0.010	0.20	0.30
LH	25.56 to 17.39	1,000	2.31	25	7.41	2.29	Camp	0.100	0.230	0.010	0.40	0.10
HN	17.39 to 2.94	1,000	6.59	25	5.36	2.01	Camp	0.100	0.150	0.010	0.10	0.50

a, i. e., the respiration on dark days could exceed the oxygen produced. Values for the oxygen demand from the benthal deposits, p, are shown in Table 24 and were selected as being the most reasonable value to be expected. Consideration was given to the removal of settleable solids by the sewage treatment plants, thereby, greatly reducing the p value from that found in 1964 and 1965.

River Constants—k_1, k_2 and k_3

Selection of the design values for the deoxygenation constant was based upon the type and characteristics of the waste being treated and the river characteristics of each reach. For example, the higher the degree of waste treatment, the lower would be the k_1 of the receiving water, since the more easily oxidizable organic matter would be removed first. Values of the river reaeration constant k_2 found in 1964 and 1965 were used as a basis for selection of the design values.

A minimum value of 0.01 was selected for k_3, the BOD settling rate, as being representative of conditions after sewage treatment plants are in operation. Adequate treatment should remove most of the BOD, with the result that very little BOD will settle out below the treatment plant. A summary of all design k values is given in Table 24.

Initial BOD Load and Deficit

The intial BOD loads below the treatment plants were computed by adding the residual loads above the plant to that discharged. If any major tributary entered the river, the BOD load from this source was also considered.

Values for the residual load were determined from the calculations for the upstream reach in all cases except for Franklin, New Hampshire, where ultimate BOD values for the Winnipesaukee and Pemigewasset Rivers were assumed to be 3.00 ppm. Projected population data from available engineering reports were used to determine the 1985 sewage treatment plant loads. Industrial loadings were assumed to have a growth commensurate with that of the populations. Tributary stream loadings were based upon past sampling data and consideration of future waste treatment, where applicable, with a minimum background ultimate BOD value of 2.00 ppm being used for "clean streams". The treatment plant flow was based upon the average daily design flow for 1985. Bottle k_1 values determined from 1964 and 1965 data were used to compute the ultimate BOD values. Design river flow and L_a values are shown in Table 24, while flows and ultimate BOD values, L, for the tributaries are listed in Table 25.

Oxygen deficit values were determined in a manner similar to that used for the BOD loads. All tributary streams were considered to have the same temperature as that of the Merrimack River. An oxygen saturation value of 85 per cent was used for all "clean water" streams, and sewage treatment plants were assumed to have an effluent dissolved oxygen value of 1.00 ppm. Calculations from the previous reach yielded the deficit value for the Merrimack River prior to receiving the effluent. At Franklin, New Hampshire, the Merrimack River, after

TABLE 25

TRIBUTARY PARAMETERS

TRIBUTARY	ASSUMED LOCATION OF DISCHARGE	FLOW CFS	L PPM	D PPM	PER CENT SATURATION
Pemigewasset R. plus Winnipesaukee R.	Franklin	580	3.00	---	---
Miscellaneous	Franklin	15	2.00	---	---
Miscellaneous	Penacook	10	2.00	1.70	85
Contoocook R.	Penacook	110	4.00	1.28	80
Miscellaneous	Concord	5	2.00	1.26	85
Soucook R.	Hooksett	5	2.00	1.26	85
Miscellaneous	Hooksett	5	2.00	1.26	85
Suncook R.	Hooksett	10	2.00	1.26	85
Miscellaneous	Manchester	5	2.00	1.26	85
Piscataquog R.	Manchester	15	2.00	1.26	85
Souhegan R.	Manchester	10	3.50	2.93	65
Souhegan R.	Nashua	5	3.50	2.93	65
Nashua R.	Nashua	90	5.00	3.38	60
Concord R.	Lowell	50	6.50	2.93	65

mixing, was considered to be at 75 per cent of saturation. Table 24 shows the initial deficits, D_a, used on the Merrimack River, while Table 25 lists the deficits assumed at the mouth of the tributaries.

Estuary Analysis

Estuary analysis was conducted using equations 5, 6, 7 and 8, which were discussed in the analysis of river parameters of 1964-1965. Values of t and U were obtained from time of flow information. An e value of 3.0 square miles per day was used.

Design Calculations

The reaches from Manchester to Newburyport were analyzed by means of the Camp equations, 1, 2, 5, 6, 7 and 8. The four reaches above Manchester, FP, PC, CH and HM, were analyzed by the Streeter-Phelps equations, 3 and 4.

Due to the additional benefits derived from secondary treatment plants and to the future water usage that can be expected in the Merrimack River Valley, a minimum of secondary treatment was assumed for all sewage treatment plants. For purposes of design calculations the efficiency of treatment plants was assumed to be 85 per cent removal of the influent BOD.

With the parameters of Table 24 established for design conditions, calculation began at Franklin, New Hampshire, with the selected background values and proceeded downstream reach by reach. Figure 45 presents the 1985 design oxygen sag curves from Franklin to Newburyport,

MERRIMACK RIVER
1985 DESIGN CONDITIONS

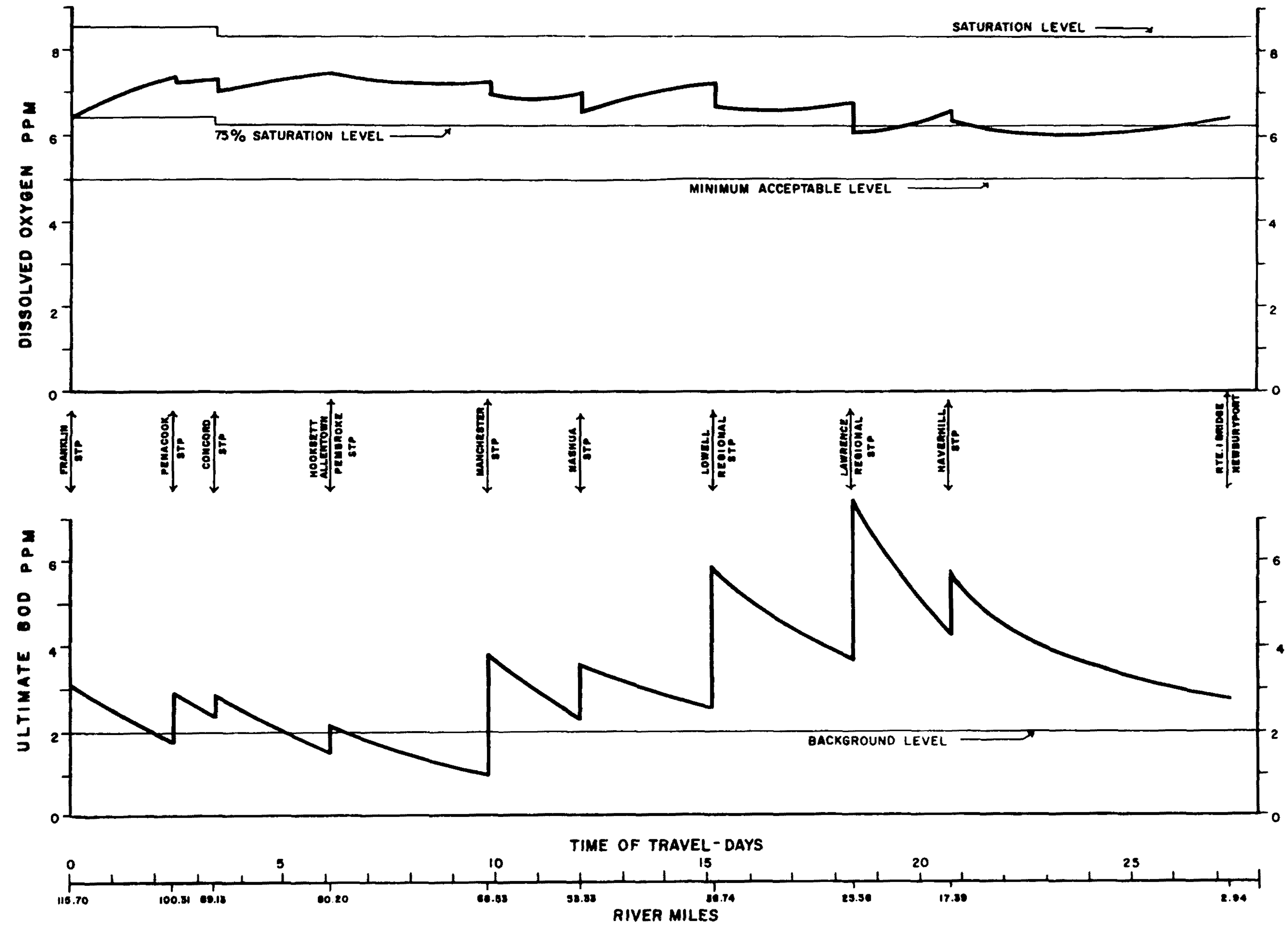


FIGURE 45

Massachusetts, as determined by the Streeter-Phelps equations above Manchester, New Hampshire, and the Camp equations below. Whenever the calculated ultimate BOD level dropped below the minimum background value of 2.00 ppm, the minimum value of 2.00 ppm was used as the background figure for the next sewage treatment plant.

Two additional lines are shown in the graph. The first line emphasizes the 5.00 ppm value of dissolved oxygen, a value that most water pollution control agencies have adopted as the minimum DO that is adequate to maintain the maximum potential warm water sport fish population. Both Massachusetts and New Hampshire have adopted 5 ppm as one of the minimum standards of quality for Class C waters. One of the definitions of Class C water is: "suitable habitat for... common food and game fishes indigenous to the region." The second line denotes the 75 per cent of the saturation value for dissolved oxygen at the design temperature. A minimum value of 75 per cent of saturation has been adopted by Massachusetts and New Hampshire as a requirement for Class B waters. This standard states in part: "...suitable for bathing and recreation, irrigation and agricultural uses...good fish habitat...good esthetic value. Acceptable for public water supply with filtration and disinfection." It is apparent from Figure 45 that this condition of Class B water can be met from the confluence of the Pemigewasset and Winnipesaukee Rivers at Franklin, New Hampshire, to the Lawrence, Massachusetts, sewage treatment plant. Below Lawrence and Haverhill, the dissolved oxygen would drop to 73 per cent of saturation. However, this value would not be low enough to prevent any of the above stated uses, as established by the two states, for Class B water.

A comparison of the dissolved oxygen levels observed in 1964-65, Figure 43, with the 1985 design conditions shows the obvious improvement when treatment is initiated.

FUTURE WATER QUALITY

EXISTING CLASSIFICATION FOR FUTURE USE

Up to this time, New Hampshire has failed to classify the Merrimack River for its future highest use. However, the state is expected to classify the Merrimack River by June 30, 1967, as provided in the Federal Water Pollution Control Act, as amended.

On April 28, 1964, the Commonwealth of Massachusetts and the New England Interstate Water Pollution Control Commission established the future highest use classification of the Merrimack River in Massachusetts. It was agreed that Class C water would exist from the New Hampshire-Massachusetts state line to the Pawtucketville Dam in Lowell. Class C from Pawtucketville Dam to Rocks Village Bridge below Haverhill was established with a modification of dissolved oxygen to four parts per million. It was further agreed that Class B would be set from the Rocks Village Bridge to the mouth of the Merrimack River at the Atlantic Ocean. Charts showing the classification system are presented in Appendix F.

Water that is Class C is not suited for use as a public water supply, for general irrigation of crops or for bathing. However, these uses exist now in the area and will probably increase. Lowell and Lawrence use the Merrimack River in its present condition as a public water supply; Lowell only recently closed a bathing beach on the river. A number of farmers use Merrimack River water to irrigate truck crops used for consumption without cooking. Therefore, if the Merrimack River is not classified higher than Class C, the part thus classified would be unsuitable for existing uses.

SELECTION OF PROPOSED REQUIREMENTS

When establishing requirements for any body of water, there are three major considerations:

1. Requirements should provide for future population, expansion of industrial capacity, addition of new industries, and other reasonable and legitimate uses.
2. Requirements should provide for maximum beneficial use of the body of water and should not hinder economic growth.
3. Requirements should be subject to reasonable, equitable, forceful, consistent and persistent enforcement.

Both existing and future uses for the Merrimack River are given in Table 26 for each reach of the river. The uses are defined below.

Municipal Water — River water could be used as an adequate water supply with filtration and disinfection.

Industrial Water — River water could be used by most industries for processing and cooling without pre-treatment and by almost all industries when treated.

Recreation — River water use for recreation is divided into two catagories. Whole body contact use would include swimming and water skiing, while limited body contact use would include fishing,

TABLE 26

EXISTING AND POTENTIAL WATER USES IN MERRIMACK RIVER

RIVER REACH \ WATER USE	Municipal Water	Industrial Water--Processing & Cooling	Recreation--Whole Body Contact	Recreation--Limited Body Contact	Fish and Wildlife	Esthetics	Agricultural	Assimilation of Adequately Treated Waste Discharges
Franklin to Penacook				O	O	O	O	O
Penacook to Concord	O		O	O	O	O	O	O
Concord to Hooksett		X	X	O	X	O	O	O
Hooksett to Manchester	O	X	X	X	X	X	X	O
Manchester to Nashua	O	O		O	O	O	X	O
Nashua to Lowell	X	X	X	X	O	X	X	O
Lowell to Lawrence	X	X	X	X	X	X	X	O
Lawrence to Haverhill	O	X		O	O	O	X	O
Haverhill to Newburyport			X	X	O	X	X	O
Newburyport to Atlantic Ocean			X	X	X	X		O

X = Present Use

O = Potential Future Use

boating and picnicking. Neither catagory would be impaired.

Fish and Wildlife -- Fishes indigenous to the region would have a good habitat in which to grow and spawn. Wildlife, including waterfowl, would have no unnatural impediments.

Esthetics -- The river should not present an objectionable sight or odor that would reduce property values below their potential, nor create unpleasant conditions for persons using the river or walking or sitting along the banks.

Agricultural -- River water could be used for agricultural purposes without endangering the health of the consumer nor the quality of the agricultural product.

Wastewater Assimilation -- The river should be able to dilute and transport adequately treated effluents of waste treatment facilities without impairing other legitimate water uses.

The water quality requirements for each water use (Table 27) were determined. Then, the water quality criteria necessary to protect every reasonable present and future water use for each reach was selected. In order to decrease the biochemical oxygen demand and bacteria in the wastes to be discharged to the Merrimack River, to provide an effluent more esthetically acceptable to the public, and to assure multiple use of the river in the future, it will be necessary to provide secondary waste treatment or the equivalent, with disinfection, for all waste discharges. The objectives which, when achieved, would assure the availability of the river for the desired uses are contained in the part of the report on recommendations[30].

TABLE 27

CONSTITUENTS CONSIDERED FOR WATER QUALITY OBJECTIVES

CONSTITUENT \ WATER USE	Municipal Water	Industrial Water--Processing	Industrial Water--Cooling	Recreation--Whole Body Contact	Recreation--Limited Body Contact	Fish and Wildlife	Esthetics	Agricultural	Assimilation of Adequately Treated Waste Discharges
Coliform Bacteria	X			X	X			X	
Turbidity		X	X	X		X	X	X	
Color (True)	X	X		X			X		
Odor	X			X	X		X		
Temperature		X	X	X		X			X
Oil	X			X	X	X	X	X	
Floating Solids and Debris				X	X		X		
Bottom Deposits				X		X			
pH	X	X	X	X	X	X		X	X
Dissolved Oxygen	X	X		X	X	X			X
BOD									X
Ammonia Nitrogen	X	X				X			
Nitrogen (Total)							X		
Phenol-like Substances	X	X				X		X	
Phosphates (Total)	X						X		

SUMMARY AND CONCLUSIONS

INTRODUCTION

In accordance with the written request to the Secretary of Health, Education, and Welfare from the Honorable Endicott Peabody, former Governor of Massachusetts, dated February 12, 1963, and on the basis of reports, surveys or studies, the Secretary of Health, Education, and Welfare, on September 23, 1963, called a conference under the provisions of the Federal Water Pollution Control Act (33 U.S.C. 466 et seq.) in the matter of pollution of the interstate waters of the Merrimack and Nashua Rivers and their tributaries (Massachusetts - New Hampshire) and the intrastate portions of those waters within the State of Massachusetts. The conference was held February 11, 1964, in Faneuil Hall, Boston, Massachusetts. Pollution sources and the effects of their discharges on water quality were described at the conference[1].

In February 1964 the U. S. Department of Health, Education, and Welfare established the Merrimack River Project to study the Merrimack River Basin. The basic objectives were twofold:

1. Evaluation of the adequacy of the pollution abatement measures proposed for the Merrimack River within Massachusetts.
2. Development of adequate data on the water quality of the Merrimack River and its tributaries. Waters in both New Hampshire and Massachusetts were to be studied.

Headquarters for the Project were established at the Lawrence Experiment Station of the Commonwealth of Massachusetts, Lawrence, Massachusetts. The Project became operational July 1, 1964.

During the first year of operation efforts were concentrated primarily in the Massachusetts section of the Merrimack River. Second year studies were mainly of the New Hampshire sections involving suspected interstate pollution, and of the Nashua River.

Prior to initiation of the field studies, a meeting was held among representatives of the Massachusetts Department of Public Health, the R. A. Taft Sanitary Engineering Center and Project personnel concerned with the approach to be used to evaluate the adequacy of the Massachusetts pollution abatement program. It was agreed to use the basic approach used by Camp, Dresser and McKee, Consulting Engineers[(2)], but with more emphasis on certain variables considered to be weak. In addition, gaps in water quality information, such as the biological condition of the river, were to be filled.

STUDY AREA

The Merrimack River Basin lies in central New England and extends from the White Mountains in New Hampshire southward into northeastern Massachusetts. Through New Hampshire, the river flows in a southerly direction for a distance of about 45 miles upon entering Massachusetts. It then empties into the Atlantic Ocean at Newburyport, Massachusetts. The lower twenty-two miles of the river are tidal. Lands drained by the Merrimack River consist of 5,010 square miles, of which 3,800 square miles are in New Hampshire, while 1,210 square miles lie in Massachusetts.

The 1960 population within the Merrimack River Basin is estimated to be 1,072,000, of which 747,000 are in Massachusetts and 325,000 are in New Hampshire. For the most part, the population centers are located along the Merrimack River.

Precipitation is distributed fairly uniformly throughout the year, and frequent but generally short periods of heavy precipitation are common in the basin. The southeastern part of the watershed, because of its proximity to the Atlantic Ocean, does not undergo the extremes of temperature and depth of snow found in New Hampshire at the higher elevations.

POLLUTION SOURCES

The Merrimack River is polluted by the discharge of raw and partially treated municipal and industrial wastes for most of its length in New Hampshire and Massachusetts. Every day more than 120,000,000 gallons of waste water flow into the Merrimack River. The river is polluted bacteriologically, physically and chemically. This polluted condition, which has been recognized since the turn of the century[19], will become progressively worse unless effective action is taken immediately.

Coliform bacteria, equivalent to those in the raw sewage from 416,000 persons, are discharged to the Merrimack River Basin. Thirty-four per cent of the bacteria are discharged in New Hampshire, the remaining 66 per cent in Massachusetts. These equivalents are discharged by the New Hampshire communities of Allenstown, Boscawen, Concord, Derry, Franklin, Hooksett, Hudson, Manchester, Merrimack, Milford, Nashua, Pembroke, Salem and Wilton, and the Massachusetts communities of Amesbury, Andover, Ayer, Billerica, Clinton, Concord, Dracut, Fitchburg, Groton, Groveland, Haverhill, Lancaster, Lawrence, Leominster, Lowell, Marlborough, Maynard, Methuen, Newburyport, North Andover, Pepperell, Salisbury, Shirley and Westborough.

The suspended solids in the discharges to the study area are equivalent to those in the raw sewage of 1,653,000 persons. Seventy-two per cent of those solids originate in Massachusetts. Major sources of suspended solids in New Hampshire are the communities of Concord, Franklin, Manchester, Milford and Nashua, and the industries of Brezner Tanning Corp., Boscawen; Franconia Paper Corp., Lincoln; Granite State Packing Co., Manchester; Granite State Tanning Co., Nashua; Hillsborough Mills, Wilton; Merrimack Leather Co., Merrimack; and Seal Tanning Co., Manchester. Massachusetts sources are the communities of Amesbury, Andover, Fitchburg, Haverhill, Lawrence, Leominster, Lowell, Methuen, Newburyport and North Andover, and the industries of Amesbury Fibre Corp., Amesbury; Commodore Foods, Inc., Lowell; Continental Can Co., Haverhill; Falulah Paper Co., Fitchburg; Foster Grant Co., Leominster; Fitchburg Paper Co., Fitchburg; Gilet Wool Scouring Corp., Chelmsford; Groton Leatherboard Co., Groton; H. E. Fletcher Co., Chelmsford; Hoyt & Worthen Tanning Corp., Haverhill; Jean-Allen Products Co., Lowell; Lawrence Wool Scouring Co., Lawrence; Lowell Rendering Co., Billerica; Mead Corp., Lawrence; Mead Corp., Leominster; Merrimack Paper Co., Lawrence; Oxford Paper Co., Lawrence;

Southwell Combing Co., Chelmsford; St. Regis Paper Co., Pepperell; and Weyerhauser Paper Co., Fitchburg.

Sewage and industrial wastes presently discharged in the basin have an estimated biochemical oxygen demand equivalent to that in the untreated sewage of 1,422,000 persons, of which 693,000 population equivalents are discharged in New Hampshire. The following communities and industries are the major contributors of this material to the study area. In New Hampshire the communities are Concord, Franklin, Manchester, Milford and Nashua, and the industries are Foster Grant Co., Manchester; Franconia Paper Corp., Lincoln; Granite State Tanning Co., Nashua; Hillsborough Mills, Wilton; Merrimack Leather Co., Merrimack; MKM Knitting Mills, Inc., Manchester; M. Schwer Realty Co., Manchester; Seal Tanning Co., Manchester; Stephen Spinning Co., Manchester; and Waumbec Mills, Inc., Manchester. In Massachusetts the communities are Amesbury, Andover, Fitchburg, Haverhill, Lawrence, Leominster, Lowell, Methuen, Newburyport, North Andover and Westborough, and the industries are Amesbury Fibre Corp., Amesbury; Commodore Foods, Inc., Lowell; Continental Can Co., Fitchburg; Falulah Paper Co., Fitchburg; Fitchburg Paper Co., Fitchburg; Foster Grant Co., Leominster; Gilet Wool Scouring Corp., Chelmsford; Groton Leatherboard Co., Groton; Hollingsworth & Vose Co., Groton; Hoyt and Worthen Tanning Corp., Haverhill; Lawrence Wool Scouring Co., Lawrence; Lowell Rendering Co., Billerica; Mead Corp., Lawrence; Mead Corp., Leominster; Merrimack Paper Co., Lawrence; No. Billerica Co., Billerica; Oxford

Paper Co., Lawrence; Simonds Saw and Steel Co., Fitchburg; Southwell Combing Co., Chelmsford; St. Regis Paper Co., Pepperell; Suffolk Knitting Co., Lowell; Vertipile, Inc., Lowell; and Weyerhauser Paper Co., Fitchburg.

Discharges, other than bacteria, suspended solids or oxygen demanding material, include color producing waste discharges by the Franconia Paper Corp., Lincoln, New Hampshire; plating wastes probably containing copper and cyanide by The Sanders Associates, Nashua, New Hampshire; 2,380 pounds of grease per day by the Southwell Combing Co., Chelmsford, Massachusetts; 3,120 pounds of grease per day by the Gilet Wool Scouring Corp., Chelmsford, Massachusetts; periodic dumping of dye by the Roxbury Carpet Co., Framingham, Massachusetts; and 860 pounds of grease per day by the Lawrence Wool Scouring Co., Lawrence, Massachusetts.

WATER USES

The Merrimack River is the municipal water supply for Lowell and Lawrence, Massachusetts. As the population in the basin multiplies, an increasing number of communities will be turning to the Merrimack River to meet their water needs. Construction and efficient operation of well designed sewage treatment plants will ensure adequate water quality to enable the municipalities and industries to utilize this abundant and inexpensive source of water.

Extensive use of the Merrimack River water is presently being made by the basin's industries. This use is limited mainly to flow-through applications, cooling water, power generation and waste transport, with very little consumptive use. Sand filters and other treatment methods are often employed by industries to precondition the water. It would not be unreasonable to expect an increase in industrial development once the basin communities can offer improved water quality to both management and employees for process water and recreational use.

Merrimack River water is used for irrigation of truck crops along most of its banks, with a concentration of farms occurring between Manchester, New Hampshire, and Lawrence, Massachusetts. Following construction of adequate waste treatment facilities, irrigation water would have a lower bacterial density, resulting in a reduced health hazard.

Recreational use of the main stem Merrimack River is severely restricted due to its polluted condition. Fishing is limited by an environment unsuitable for game fish common to the area and by public abhorrence to fishing in waters polluted with raw sewage and other waste materials. Proper control of this pollution would enable 10.5 million people within a day's drive of the river and thousands in the rest of the country to fully utilize the tremendous fish, wildlife and recreational potential of the Merrimack River Basin.

For the basin area, a minimum estimate of the potential resources lost due to pollution is $37,000,000 for the year 1964.

The income lost from various sources is:

Commercial Shellfish	$ 300,000
Recreation Visitor Income	21,300,000
Increased Property Value	9,100,000
Increased Tax Revenue	5,500,000
Miscellaneous	800,000
	$ 37,000,000

A more complete and detailed survey would probably indicate an annual loss in the range of 60 to 70 million dollars, or an additional income of sixty-five dollars per year for every man, woman and child in the basin.

EFFECTS OF POLLUTION ON WATER QUALITY

Concentrated water quality studies in the Merrimack River Basin were conducted during July and August of 1964 and 1965. Other supplemental studies were made throughout the year. Pollution of the Merrimack River and its tributaries was evaluated on the basis of coliform bacteria, dissolved oxygen, biochemical oxygen demand, and temperature. Time of travel data was obtained from Rhodamine B dye studies.

The temperature of the Merrimack River during the summer months averaged 23°C. There was only one significant source of heat pollution, that being the Public Service Company of New Hampshire's power generating facilities at Bow, New Hampshire. A temperature increase of 3°C was apparent below the discharge area. Any expansion of this plant, or construction of new facilities in the basin, should provide for cooling of the waste discharges, thereby preventing excessive temperature build ups.

Biochemical oxygen demand (BOD) crossing the state line from New Hampshire into Massachusetts amounted to 28,800 pounds per day during August 1965. This is equivalent to the discharge of raw sewage from a city of 169,000 persons.

Substantial amounts of BOD are discharged by the industries and communities of Concord, Manchester and Nashua, New Hampshire, and Lowell, Lawrence and Haverhill, Massachusetts, causing serious reduction in the dissolved oxygen content of the Merrimack River during the summer months. In June, July, August and September of 1964 and 1965, more than half of the points sampled had an average dissolved oxygen content of less than 5.0 ppm. A value of 5.0 ppm is considered by most state water pollution control agencies to be the minimum value to be maintained in order to provide for the maximum potential warm water sport fish population. It is also one of the requirements for Class C water, as established by the New England Interstate Water Pollution Control Commission.

A depletion of the oxygen resource of a river will reduce or eliminate aquatic life which serves as food for fishes. The biological study of the Merrimack River[8] shows that those benthic organisms sensitive in their response to pollution were absent in the lower fifty-seven miles of the Merrimack River. In only four extremely short portions of the river, consisting of less than fifteen miles out of the total river mileage of 115, did the river recover enough from its despoiled condition to permit a small number of sensitive organisms to exist.

With the exception of a short section of the river below Hooksett, New Hampshire, bacterial pollution presents a health hazard for all full body contact recreation, such as swimming and water skiing, from Franklin, New Hampshire, to Newburyport, Massachusetts. Below Manchester and Nashua, New Hampshire, and Lowell, Lawrence and Haverhill, Massachusetts, coliform densities in excess of 1,000,000 per 100 ml were not uncommon, being found as high as 9,200,000 per 100 ml. Recommended limits of coliform densities for water contact sports range from 50 to 5,000 per 100 ml in various states.

Nashua and Hudson, New Hampshire, contributed over 98 per cent of the coliform bacteria crossing the New Hampshire-Massachusetts state line during warm, low flow periods of the year. However, with colder water temperatures and increased flows in the autumn, the Nashua-Hudson portion at the state line was reduced to 50 per cent; Manchester, New Hampshire, was responsible for 25 per cent of the total. The discharge of raw sewage to the study area is a health hazard to the residents in the downstream communities as well as to the local population.

Vegetables that are ordinarily eaten without cooking are irrigated at several truck farms with water from the Merrimack River. Fecal coliforms were present on vegetables grown from farms irrigating with Merrimack River water in a significantly greater number of cases than on vegetables that were not irrigated with the river water.

While coliform bacteria densities indicate the magnitude of potential disease-producing organisms, detection of pathogenic Salmonella bacteria is positive proof of the presence of such organisms. Typhoid fever, gastroenteritis and diarrhea are but a few of the many diseases of man caused by these bacteria. Salmonella were consistently recovered from the Merrimack River in both New Hampshire and Massachusetts, indicating that ingestion of untreated Merrimack River water is a definite health hazard. Salmonella organisms were isolated during each test made at the Lowell and Lawrence water intakes. These disease producing organisms were isolated from river water having a total coliform density as low as 180 per 100 ml.

There are two major contributors of coliform bacteria to the estuary: the communities upstream of Newburyport and the two communities of Newburyport and Salisbury. Of the bacteria originating from upstream communities and reaching the estuary, 51.4 per cent emanated from the Lawrence region, 17.1 per cent from the Haverhill region and 31.4 per cent from the Amesbury region. Discharges into the estuary from existing treatment facilities in Newburyport and Salisbury significantly increase the bacterial densities near the shellfish growing areas. If the potential one million dollar shellfish harvest is to be a reality, the discharge of sewage in the greater Lawrence, Haverhill and Amesbury areas will need constantly and efficiently operating disinfection facilities. In addition, the communities of Newburyport and Salisbury will need to discharge their wastes, adequately treated, to the Atlantic Ocean instead of to the estuary.

Phosphate and nitrogen concentrations in the Merrimack River are far in excess of the amount needed to produce nuisance algal blooms. In order to reduce taste and odor problems with municipal water supplies taken from the river and to improve the esthetic quality of the water, the concentration of these nutrients should be reduced.

Severe to moderate pollution exists on several tributaries of the Merrimack River. These include the Souhegan River near Wilton and Milford, New Hampshire; Beaver Brook near Derry, New Hampshire, and Lowell, Massachusetts; the Assabet River below Westborough, Hudson and Maynard, Massachusetts; Hop Brook (a Sudbury River tributary) below Marlborough, Massachusetts; the Concord River below Billerica and in Lowell, Massachusetts; the Spicket River in Salem, New Hampshire, and Methuen and Lawrence, Massachusetts; the Shawsheen River below Bedford and in Andover, Massachusetts; and the Powwow River below Amesbury, Massachusetts.

Gross oxygen production from photosynthesis in the Merrimack River was between 0.8 and 2.0 ppm per day during the summers of 1964 and 1965. These values were obtained by the use of light and dark bottle tests between Manchester, New Hampshire, and Newburyport, Massachusetts. The rate of oxygen production on cloudy days was found to be approximately one-tenth the value found on sunny days.

In the sixty-seven mile reach of the Merrimack River between Manchester and Newburyport, there are approximately 16,900,000 cubic feet of settled solid material, 7,900,000 of which are located between Lowell and Lawrence, and 7,800,000 between Haverhill and Newburyport. The oxygen demand of these benthal deposits in the overflowing waters ranged from 0.2 to 1.0 ppm per day.

Oxygen balance studies were carried out, and the variables affecting the oxygen sag curves were obtained for each of six reaches below Manchester, New Hampshire. These variables were adjusted to reflect the future conditions in 1985 when a secondary waste treatment program for the Merrimack River would be in effect. Dissolved oxygen calculations for the 1985 conditions indicated that oxygen levels of 75 per cent of saturation (Class B water as established by the New England Interstate Water Pollution Control Commission) can be met from Franklin, New Hampshire, to Lawrence, Massachusetts, and from Amesbury, Massachusetts, to the Atlantic Ocean.

Existing and potential future water uses in the Merrimack River indicate that the river will be used for a variety of purposes. Consideration was given to water quality limits for various constituents that would affect the suitability of the stream for each water use. In order to decrease the biochemical oxygen demand and bacteria in the wastes to be discharged to the Merrimack River, to provide an effluent more esthetically acceptable to the public, to assure the existing and future desired uses of the river by the public and to protect the health and welfare of the public, it will be necessary to provide secondary waste treatment or equivalent, with disinfection, for all waste discharges. If the recommendations of this report (Part I —Summary, Conclusions and Recommendations, reference 30) are followed, water quality of sufficient purity to accommodate the various water uses will be attained.

REFERENCES

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APPENDICES

APPENDIX A

REFERENCE POINTS FOR MERRIMACK RIVER

RIVER STATIONS FC-0.0 to CH-0.0
RIVER MILES 115.70 to 90.23

STATION	MILE	
FC-0.0	115.70	Confluence of Pemigewasset & Winnepesaukee
0.1	115.53	Proposed Franklin STP outfall
0.2		
0.3	114.70	USGS Gauging Station
0.4		
0.5		
0.6		
0.7	111.55	Cross Brook
0.8		
0.9		
FC-1.0	109.20	Glines Bk.
1.1		
1.2	108.65	
1.3		
1.4	105.17	Tannery Bk.
1.5	105.13	
1.6	105.07	Boscawen Bridge
1.7		
1.8		
1.9	100.89	Penacook Bridge
FC-2.0	100.71	Contoocook R. (South mouth)
2.1		
2.2	100.31	Proposed Penacook STP outfall
2.3		
2.4		
2.5		
2.6	98.78	Sewells Falls Road Bridge
2.7		
2.8		
2.9		
FC-3.0	97.83	Sewells Falls Dam
3.1		
3.2		
3.3	94.34	B & M R. R. Bridge, East Concord
3.4	94.21	I 93 Bridge
3.5		
3.6		
3.7	91.60	Route 4-202 bridge
3.8		
3.9		
CH-0.0	90.23	Route 3 bridge

RIVER STATIONS CH-0.0 to HM-1.0
RIVER MILES 90.23 to 78.22

STATION	MILE	
CH-0.0	90.23	Route 3 bridge
0.1		
0.2		
0.3	89.13	Proposed Concord STP Outfall
0.4		
0.4		
0.6	87.83	Bow Junction
0.7	87.61	Turkey River
0.8		
0.9		
CH-1.0	86.80	Garvins Falls Dam
1.1	86.50	**Power lines**
1.2		
1.3	85.80	Soucook R.
1.4		
1.5	85.15	Meetinghouse Bk.
1.6		
1.7	84.00	**Public Service Co. Power Station**
1.8	83.80	
1.9	83.68	Bow Bog Bk.
CH-2.0	83.32	
2.1	83.30	Sewer Outfall, Pembroke
2.2	82.90	Suncook R.
2.3		
2.4		
2.5		
2.6		
2.7	81.81	N. end of Island
2.8		
2.9	81.20	**Launch site, Hooksett**
HM-0.0	81.05	Hooksett Dam
0.1		
0.2	80.60	Hooksett Bridge
0.3	80.20	Est. proposed Hooksett STP outfall
0.4	80.15	**Brickyard Bk.**
0.5		
0.6	79.24	**Unnamed Bk., above Peters Brook, east bank**
0.7		
0.8	78.50	**Unnamed Bk., above Peters Brook, west bank**
0.9		
HM-1.0	78.22	Peters Bk.

RIVER STATIONS HM-1.0 to MN-2.0
RIVER MILES 78.22 to 68.05

STATION	MILE	
HM-1.0	78.22	Peters Bk.
1.1		
1.2	77.40	Dalton Bk.
1.3		
1.4	76.79	Messer Bk.
1.5		
1.6	76.37	Power Lines
1.7	75.85	
1.8	75.75	
1.9		
HM-2.0	74.90	Milestone Bk.
2.1		
2.2		
2.3	74.17	Center of WGIR Radio towers
2.4		
2.5		
2.6	73.70	Black Bk.
2.7	73.57	Launch site (Ski Club)
2.8		
2.9	73.20	Amoskeag Bridge
MN-0.0	73.14	Amoskeag Dam
0.1		
0.2		
0.3		
0.4		
0.5		
0.6		
0.7		
0.8	71.30	Piscataquog R.
0.9		
MN-1.0	71.07	Queen City Bridge
1.1	71.00	
1.2		
1.3	69.85	Bowman Bk.
1.4		
1.5		
1.6	69.04	USGS Gauging Station
1.7	68.90	I-93 bridge
1.8		
1.9	68.53	Proposed Manchester STP outfall
MN-2.0	68.05	Goffs Falls, B&M R. R. Bridge

RIVER STATIONS MN-2.0 to NL-1.0
RIVER MILES 68.05 to 52.72

STATION	MILE	
MN-2.0	68.05	Goffs Falls B&M R. R. bridge
2.1		
2.2	67.70	Cohas Bk.
2.3		
2.4	67.06	Little Cohas Bk.
2.5	66.30	Sebbins Bk.
2.6	65.11	
2.7	64.20	Colby Bk.
2.8	63.00	200 yds. above power lines
2.9	62.89	Power lines
MN-3.0	62.35	Souhegan River
3.1	61.60	
3.2	61.55	
3.3	61.18	Litchfield Town Hall
3.4	60.71	Noticook Bk. (Thorntons Ferry)
3.5	60.36	Nesenkeag Bk.
3.6		
3.7	59.35	N. end of Islands
3.8	59.20	First point below Falls
3.9	58.65	Little Nesenkeag Bk.
MN-4.0	58.10	Rodonis Farm, Litchfield, N. H.
4.1		
4.2	57.65	Pennichuck Bk.
4.3	56.84	
4.4	56.43	
4.5	55.75	Second power line above Nashua R.
4.6	55.06	
4.7	55.00	First power line above Nashua R.
4.8		
4.9	54.80	Nashua R.
NL-0.0	54.55	Route 111, Hudson-Nashua Bridge
0.1	54.25	Outfall
0.2	54.16	
0.3	53.80	
0.4	53.65	Outfall
0.5	53.62	First power lines below Nashua R.
0.6	53.50	Salmon Bk.
0.7	53.33	Nashua STP Outfall
0.8	53.17	
0.9	52.81	
NL-1.0	52.72	Second power lines below Nashua R.

RIVER STATIONS NL-1.0 to NL-5.0
RIVER MILES 52.72 to 40.75

STATION	MILE	
NL-1.0	52.72	Second power lines below Nashua R.
1.1		
1.2		
1.3	51.98	
1.4		
1.5	51.53	
1.6	51.06	Spit Bk.
1.7	49.82	N. H.-Mass. state line
1.8	49.39	
1.9	49.10	Limit Bk.- Musquash Bk.
NL-2.0	48.76	Foot of Lakeview Ave.,
2.1	48.74	
2.2		
2.3		
2.4		
2.5	48.15	Robinson's picnic grounds
2.6		
2.7		
2.8		
2.9	47.43	Bridge Meadow Bk.
NL-3.0	47.35	Tyngsboro Bridge
3.1		
3.2	46.66	Lawrence Bk.
3.3		
3.4	46.20	
3.5	45.75	0.3 miles above Tyngs Island
3.6	45.45	NW tip Tyngs Island
3.7	44.73	SE tip Tyngs Island
3.8		
3.9	44.05	Scarlet Brook
NL-4.0	43.47	Lowell Water Intake, Deep Bk.
4.1	43.16	Stony Bk.
4.2	42.90	
4.3	42.66	Pipe discharge, Lowell Water Treatment Plant
4.4	42.22	
4.5	42.07	Boat launch
4.6	41.57	Black Bk.
4.7	41.10	Beach house
4.8	41.00	Clay Pit Bk.
4.9	40.90	
NL-5.0	40.75	Lowell Boat Club

RIVER STATIONS NL-5.0 to LL-3.0
RIVER MILES 40.75 to 35.00

STATION	MILE	
NL-5.0	40.75	Lowell Boat Club
5.1	40.70	Pawtucket Canal
5.2	40.65	Dam N. Shore
5.3	40.60	Dam Mid-Point
5.4	40.56	Dam S. Shore
5.5		
5.6	39.80	Beaver Brook
5.7		
5.8		
5.9	39.00	
LL-0.0	38.75	Concord R.
0.1	38.53	USGS Gauging Station wire
0.2	38.49	Route 38-110 Bridge (Hunt Falls bridge)
0.3	38.48	USGS Gauging Station structure
0.4		
0.5		
0.6		
0.7		
0.8		
0.9		
LL-1.0	37.45	
1.1		
1.2		
1.3		
1.4		
1.5	36.83	Outfall
1.6	36.79	
1.7	36.74	Proposed Lowell STP outfall
1.8		
1.9		
LL-2.0	36.53	
2.1	36.36	Richardson Bk.
2.2		
2.3		
2.4	35.97	Trull Brook
2.5		
2.6		
2.7		
2.8	35.57	Nickel Mine Bk.
2.9		
LL-3.0	35.00	Power lines

RIVER STATIONS LL-3.0 to LL-7.0
RIVER MILES 35.00 to 29.81

STATION	MILE	
LL-3.0	35.00	Power lines
3.1		
3.2		
3.3		
3.4		
3.5		
3.6	34.39	Essex-Middlesex County line
3.7		
3.8		
3.9	33.93	
LL-4.0	33.90	Foot of Wheeler St., Methuen, Mass.
4.1		
4.2		
4.3		
4.4		
4.5	33.20	S. end Pine Island
4.6	33.03	Fish Bk.
4.7		
4.8	32.82	N. end Pine Island
4.9		
LL-5.0	32.37	Merrimack Park Drive-In, Methuen
5.1	32.30	Sawyer Brook
5.2		
5.3		
5.4		
5.5	31.92	Mill Pond, Bartlett Bk.
5.6		
5.7		
5.8	31.74	
5.9	31.70	
LL-6.0	31.60	I-93 Bridge
6.1		
6.2	31.14	
6.3		
6.4		
6.5	30.65	Marina
6.6		
6.7		
6.8	30.05	Power lines
6.9		
LL-7.0	29.81	Lawrence Water Intake

RIVER STATIONS LL-7.0 to LH-2.0
RIVER MILES 29.81 to 23.43

STATION	MILE	
LL-7.0	29.81	Lawrence Water Intake
7.1		
7.2	29.68	
7.3		
7.4		
7.5	29.49	
7.6		
7.7	29.20	Launch Area, Riley Park, Lawrence
7.8		
7.9	29.03	Lawrence Floats
LL-8.0	28.99	Essex Dam
8.1		
8.2		
8.3		
8.4		
8.5		
8.6	28.20	So. Union St. Bridge
8.7		
8.8	27.85	Spickett R.
8.9		
LH-0.0	27.46	I 495 Bridge
0.1	27.45	Shawsheen R.
0.2		
0.3	27.15	Cochichewick R., Sutton Pond
0.4	27.11	
0.5	27.07	
0.6	27.02	Lawrence Incinerator
0.7		
0.8	26.81	County Training School
0.9		
LH-1.0	26.45	
1.1	25.93	
1.2	25.56	Proposed Lawrence STP outfall
1.3	25.35	Western Electric outfall
1.4		
1.5	24.86	
1.6	24.44	
1.7	24.32	
1.8	24.00	
1.9	23.53	Power lines
LH-2.0	23.43	

RIVER STATIONS LH-2.0 to HN-2.0
RIVER MILES 23.43 to 13.47

STATION	MILE	
LH-2.0	23.43	
2.1	23.35	I 495 Bridge
2.2	22.78	S. end Kimball Island
2.3	22.83	Bare Meadow Bk.
2.4	22.02	
2.5	21.85	Creek Bk.
2.6	21.25	I 495 Bridge
2.7	20.95	N. end Kimball Island
2.8	20.77	
2.9	20.55	
LH-3.0	20.20	Foot of Maxwell St. Haverhill, Mass.
3.1	20.15	
3.2		
3.3		
3.4	19.62	Moody School
3.5		
3.6		
3.7	19.12	Greenleaf Bridge
3.8	19.08	R. R. bridge
3.9		
HN-0.0	18.85	Little R.
0.1	18.51	Main St. Bridge, Route 125
0.2	17.75	Buoy 65
0.3	17.48	Buoy 63
0.4	17.39	Proposed Haverhill STP Outfall
0.5	16.79	Buoy 61
0.6	16.40	Buoy 60
0.7	16.23	Buoy 58
0.8	16.03	Buoy 57
0.9	15.70	Groveland Br., Route 113
HN-1.0	15.40	Boat dock, Haverhill Riverside Airport
1.1		
1.2	15.00	
1.3		
1.4	14.74	Buoy 55
1.5	14.55	East Meadow R.
1.6	14.30	Buoy 53
1.7		
1.8	13.82	Buoy 51
1.9		
HN-2.0	13.47	Buoy 49 near Pleasant St., West Newbury, Mass.

RIVER STATIONS HN-2.0 to HN-6.0
RIVER MILES 13.47 to 2.94

STATION	MILE	
HN-2.0	13.47	Buoy 49 near Pleasant St., West Newbury, Mass.
2.1	12.98	Buoy 47
2.2		
2.3	12.28	Buoy 45
2.4	12.21	
2.5	11.96	Buoy 44
2.6	11.80	Rocks Village Bridge
2.7	11.50	Buoy 43
2.8	11.13	Buoy 41
2.9	10.63	Buoy 39
HN-3.0	10.36	Buoy 37, proposed STP outfall, Merrimacport, Mass.
3.1	10.10	Cobbler Bk., Buoy 35
3.2	9.70	Power lines
3.3	9.37	Buoy 33
3.4	8.80	Indian River, Buoy 32
3.5	8.11	Buoy 30
3.6	7.80	Artichoke R.
3.7	7.76	Buoy 29
3.8	7.28	Buoy 28
3.9	7.13	Proposed STP outfall, Amesbury
HN-4.0	6.92	Foot of Martin Rd., Amesbury
4.1		
4.2		
4.3	6.40	Powwow R.
4.4		
4.5	6.20	Buoy 26
4.6		
4.7	5.96	Buoy 24 and 25
4.8		
4.9	5.56	Buoy 21
HN-5.0	5.50	I-95 Bridge
5.1	5.19	Chain-of-Rocks Bridge
5.2		
5.3	4.85	Buoy 19
5.4	4.70	Buoy 17
5.5		
5.6	4.15	Buoy 16A
5.7		
5.8	3.40	Buoy 16
5.9		
HN-6.0	2.94	B&M R. R. Bridge

RIVER STATIONS HN-6.0 to HN-8.0
RIVER MILES 2.94 to 0.00

STATION	MILE	
HN-6.0	2.94	B&M R. R. Bridge
6.1	2.91	Route 1 Bridge
6.2		
6.3	2.70	Buoy 14A
6.4		
6.5		
6.6		
6.7	2.39	Buoy 14
6.8		
6.9	2.28	American Yacht Club
HN-7.0	2.23	STP outfall, Newburyport, Mass.
7.1	2.15	Buoy 13A
7.2	2.06	North Pier
7.3	1.91	Buoy 12A
7.4	1.79	Buoy 13
7.5		
7.6	1.03	Buoy 11 and 12
7.7	0.55	Buoy 9A
7.8	0.46	Black Rock Cr.
7.9	0.15	Buoy 10
HN-8.0	0.00	90° north of Coast Guard Lighthouse

APPENDIX A

MERRIMACK RIVER ESTUARY

DATA FROM C&GS MAP #213

STATION	LATITUDE	LONGITUDE
R-1A	42° 48' 48"	70° 51' 35"
R-1B	42° 48' 37"	70° 51' 40"
R-2AA	42° 49' 02"	70° 51' 11"
R-2A	42° 48' 50"	70° 51' 10"
R-2B	42° 48' 44"	70° 51' 09"
R-2C	42° 48' 37"	70° 51' 09"
R-2D	42° 48' 32"	70° 51' 08"
R-2E	42° 48' 21"	70° 51' 10"
R-3AA	42° 49' 19"	70° 50' 20"
R-3A	42° 49' 07"	70° 50' 19"
R-3B	42° 48' 57"	70° 50' 19"
R-3C	42° 48' 48"	70° 50' 19"
R-3D	42° 48' 35"	70° 50' 18"
R-3E	42° 48' 16"	70° 50' 25"
R-3F	42° 47' 57"	70° 50' 18"
R-4DD	42° 50' 02"	70° 49' 12"
R-4CC	42° 50' 00"	70° 49' 15"
R-4BB	42° 49' 54"	70° 49' 19"
R-4AA	42° 49' 46"	70° 49' 36"
R-4A	42° 49' 23"	70° 49' 42"
R-4B	42° 49' 05"	70° 49' 48"
R-4C	42° 48' 46"	70° 49' 52"
R-5A	42° 49' 07"	70° 49' 19"
R-6A	42° 48' 54"	70° 49' 21"
R-6B	42° 48' 46"	70° 49' 39"
R-6C	42° 48' 25"	70° 49' 47"
R-6D	42° 48' 00"	70° 49' 47"
R-6E	42° 47' 51"	70° 49' 19"
R-6F	42° 47' 34"	70° 48' 49"
R-6G	42° 47' 03"	70° 48' 47"
R-6H	42° 46' 38"	70° 48' 58"
R-6I	42° 46' 27"	70° 48' 57"
R-6J	42° 46' 04"	70° 48' 09"
TC-1	42° 49' 37"	70° 52' 33"
TC-2	42° 49' 51"	70° 52' 08"

APPENDIX A

RIVER MILES OF SELECTED TRIBUTARIES

SAMPLE STATION	RIVER MILE	LOCATION
Souhegan River (confluence with Merrimack River 62.35 - 0.00)		
	28.6	Rte. 31 Bridge, Greenville
So-1.0	21.4	Rte. 31 - 101 Bridge, Wilton
SB	20.2 - 1.4	Stony Brook at Rte. 31 Bridge, Wilton
So-2.0	20.2	Confluence with Stony Brook, Wilton
So-3.0	18.2	North Purgatory Road Bridge, Milford
So-3.5	15.6	Confluence with Tucker Brook, Milford
So-3.8	14.8	
	13.3	Rte. 13 - 101 Bridge, Milford
So-5.0	11.8	Riverside Cemetery, Milford
So-6.0	10.6	Ponemah Bridge, Amherst
So-7.0	8.4	Honey Pot Pond Bridge, Amherst
	6.8	Amherst-Merrimack Town Line
So-8.0	6.5	Severns Bridge, Merrimack
So-8.6	3.1	Turkey Hill Bridge, Merrimack
	1.3	USCG Gaging Station, Merrimack
So-9.0	0.7	Everett Turnpike Bridge, Merrimack
	0.3	Rte. 3 Bridge, Merrimack
	0.0	Confluence with Merrimack River
Beaver Brook (confluence with Merrimack River 39.80 - 0.00)		
BB-1.0	23.6	Fordway Street bridge, Derry
BB-2.0	22.2	Cemetery Road bridge, Derry
BB-3.0	15.1	Rte. 128 bridge, Pelham
BB-4.0	6.6	Willow Street Bridge, Pelham
	4.2	N. H. - Mass. State Line
BB-5.0	3.9	Dirt farm road, Dracut
BB-6.0	1.2	Phineas Street bridge, Lowell
	0.0	Confluence with Merrimack River

APPENDIX A (Continued)

SAMPLE STATION	RIVER MILE	LOCATION
Concord River (confluence with Merrimack River 38.75 - 0.0)		
	15.4	Confluence of Assabet and Sudbury Rivers, Concord
C-1.0	14.7	Monument Street Bridge, Concord
C-2.0	13.7	Confluence with Saw Mill Brook, Concord
C-3.0	12.2	Near Davis Hill, Concord
C-5.0	10.9	Rte. 25 bridge, Bedford-Carlisle
C-6.0	8.8	Rte. 4 bridge, Billerica
C-7.0	5.9	Rte. 3A bridge, Billerica
C-8.0	2.5	I 495 bridge, Lowell
C-9.0	0.8	Rogers Street bridge, Lowell
	0.0	Confluence with Merrimack River
Assabet River (confluence with Concord River 15.4 - 0.0)		
A-0.5	26.8	Maynard Street bridge, Westborough
	26.4	Sewage treatment plant, Westborough
A-1.0	26.0	Rte. 9 bridge, Westborough
	25.3	Sewage treatment plant, Shrewsbury
A-2.0	24.9	Rte. 135 bridge, Westborough
A-3.0	23.6	Brigham Street bridge, Northborough
A-3.5	22.8	East Main Street bridge, Northborough
A-4.0	22.0	Allen Street bridge, Northborough
A-4.5	20.8	Robin Hill Road bridge, Marlborough
A-5.0	16.6	Park footbridge, Hudson
A-6.0	14.2	Cox Street bridge, Hudson
	14.0	Sewage treatment plant, Hudson
A-7.0	12.9	Gleasondale bridge, Hudson
A-8.0	10.9	Boon Road bridge, Stow
A-9.0	7.2	Rte. 27 bridge, Maynard
	6.2	Sewage treatment plant, Maynard
A-9.5	4.2	Rte. 62 bridge, West Concord
A-9.8	2.2	Rte. 2 bridge, Concord
	0.0	Confluence with Sudbury River Origin of the Concord River

APPENDIX A (Continued)

SAMPLE STATION	RIVER MILE	LOCATION
Sudbury River (Confluence with Concord River 15.4 - 0.0)		
Su-1.0	15.5	Central Street bridge, Framingham, Mass.
Su-1.5	15.0	Concord Street bridge, Framingham
Su-2.0	14.8	Danforth Street bridge, Framingham
Su-3.0	13.0	Potter Road bridge, Framingham-Wayland
	9.6	Hop Brook, Wayland
Su-9.8	0.6	Concord Academy bridge, Concord
	0.0	Confluence with Assabet River. Origin of Concord River
Hop Brook (Confluence with Sudbury River 9.6 - 0.0)		
HB-1.0	9.6	Rte. 20 bridge, Marlborough
HB-2.0	8.5	Old Boston Post Road bridge, Sudbury
HB-3.0	2.1	Rte. 20 bridge, Sudbury
	0.0	Confluence with Sudbury River
Spicket River (Confluence with Merrimack River 27.85 - 0.0)		
Sp-1.0	12.2	Widow Harris Brook, Salem, New Hampshire
Sp-2.0	10.9	Bridge Street bridge, Salem
Sp-3.0	7.5	Rte. 28 bridge, Salem
	6.4	N. H. - Mass. State Line
	6.1	Policy Brook, Methuen, Mass.
Sp-4.0	6.0	Hampshire Road bridge, Methuen
Sp-5.0	3.5	Lowell Street bridge, Methuen
Sp-6.0	0.2	Canal Street bridge, Lawrence
	0.0	Confluence with Merrimack River
Policy Brook (Confluence with Spicket River 6.1 - 0.0)		
PB-2.0	2.8	Rte. 28 bridge, Salem, New Hampshire
PB-3.0	1.6	Policy Road bridge, Salem
	0.0	Confluence with Spicket River

APPENDIX A (Continued)

SAMPLE STATION	RIVER MILE	LOCATION
Shawsheen River (Confluence with the Merrimack River 27.45-0.0)		
Sh-1.0	20.0	Route 62 bridge, Bedford
Sh-2.0	18.1	Lowell Street bridge, Bedford
Sh-3.0	16.7	Route 3A bridge, Billerica
Sh-4.0	13.8	Route 129, Billerica-Wilmington
Sh-5.0	12.0	Main Street bridge, Tewksbury
Sh-6.0	10.8	Lowe Street bridge, Tewksbury
Sh-7.0	7.6	Ballardvalle bridge, Andover
Sh-8.0	5.6	Reservation Road bridge, Andover
Sh-9.0	4.4	Route 28 bridge, Andover
Sh-10.0	3.5	Kenilworth Street bridge, Andover
Sh-11.0	2.5	Route 114 bridge, North Andover
Sh-12.0	0.3	Sutton Street culvert, Lawrence
	0.0	Confluence with Merrimack River
Little River (Confluence with Merrimack River 18.85-0.0)		
L-1.0	7.0	North Main Street bridge, Plaistow
L-2.0	5.7	Bridge 0.1 mile below Seaver Brook, Plaistow
L-3.0	4.4	Route 121 bridge, Plaistow
	4.3	N. H.-Mass. State Line
L-3.5	3.1	Rosemount Street bridge, Haverhill
L-4.0	1.1	R.R. Bridge near St. James Cemetery, Haverhill
	0.0	Confluence with Merrimack River
Powwow River (Confluence with Merrimack River 6.40-0.0)		
	7.7	N. H.-Mass. State Line
P-1.0	7.2	Newton Road bridge, Amesbury
	4.5	N. H.-Mass. State Line
P-2.0	4.1	New bridge off Whitehall Road, South Hampton
	3.8	N. H.-Mass. State Line
P-3.0	0.7	Route 110 bridge, Amesbury
	0.0	Confluence with Merrimack River

APPENDIX B (Continued)

TEMPERATURE, DISSOLVED OXYGEN, AND BIOCHEMICAL OXYGEN DEMAND

MERRIMACK RIVER

STATION	TEMPERATURE °C				DISSOLVED OXYGEN ppm				BOD_5 ppm			
	No.	Min.	Avg.	Max.	No.	Min.	Avg.	Max.	No.	Min.	Avg.	Max.
8-4-64 thru 8-7-64												
MN-4.0	33	21	22.2	24	34	3.8	5.02	6.9	9	4.0	5.56	7.2
NL-1.0	34	19	21.7	23	34	2.9	4.93	6.9	9	2.2	5.00	7.0
NL-2.0	34	21	21.9	23	34	3.4	4.99	8.0	9	3.8	4.47	5.0
NL-3.0	32	20	21.8	23	34	3.1	5.08	6.9	9	2.4	4.53	7.2
8-11-64 thru 8-14-64												
NL-4.0	18	20	21.4	22	18	3.2	4.06	5.3	6	2.0	3.13	4.6
LL-1.0	36	20	21.6	22	36	1.5	3.20	4.9	6	5.0	5.57	6.3
LL-2.0	36	21	21.7	23	36	1.3	2.82	4.9	6	4.6	5.00	5.3
LL-3.0	36	21	21.7	22	36	1.1	2.62	4.3	6	3.6	4.48	5.7
LL-4.0	36	20	21.8	23	36	1.2	2.08	3.2	6	3.0	3.88	5.6
LL-5.0	36	21	21.9	23	36	0.9	2.12	3.8	6	2.7	3.17	4.3
LL-6.0	36	21	21.9	23	36	1.5	2.45	3.5	6	2.9	3.07	3.4
LL-7.0	36	21	21.9	22	36	0.8	2.26	3.0	6	2.4	3.07	3.9
8-25-64 thru 8-28-64												
LH-1.0	12	20	21.9	23	12	2.6	3.33	4.0	12	6.0	7.63	11.3
LH-2.0	12	20	21.8	23	12	1.0	2.28	3.2	12	6.7	8.54	11.0
LH-3.0	12	20	21.8	23	12	0.6	1.94	3.7	12	4.6	6.73	8.0
HN-1.0	30	20	22.2	23	30	0.0	0.96	2.3	7	4.0	6.36	8.7
HN-2.0	30	21	22.2	23	30	0.0	0.88	2.5	7	4.7	6.64	7.7
HN-3.0	30	21	22.0	23	30	0.2	1.55	3.2	7	3.3	6.13	8.0
HN-4.0	20	18	21.1	23	20	1.0	2.47	5.0	7	1.5	4.71	7.0
HN-5.0	16	17	20.0	23	16	1.0	3.55	6.9	7	1.0	3.64	6.7
HN-6.0	16	14	18.1	22	16	1.7	5.06	8.4	7	1.0	2.66	4.3
9-16-64												
LL-1.0	2	18	--	19	2	3.3	--	3.6	1	--	3.7	--
LL-2.0	2	19	--	19	2	3.7	--	3.7	1	--	3.7	--
LL-3.0	2	18	--	19	2	1.9	--	2.0	1	--	4.2	--
LL-4.0	2	19	--	19	2	2.4	--	2.6	1	--	4.0	--
LL-5.0	2	18	--	19	2	2.2	--	2.2	1	--	3.1	--
LL-6.0	2	19	--	19	2	1.9	--	2.1	1	--	2.9	--
LL-7.0	2	19	--	19	2	1.2	--	1.4	1	--	2.7	--

APPENDIX B (Continued)

TEMPERATURE, DISSOLVED OXYGEN, AND BIOCHEMICAL OXYGEN DEMAND

MERRIMACK RIVER

STATION	TEMPERATURE °C				DISSOLVED OXYGEN ppm				BOD_5 ppm			
	No.	Min.	Avg.	Max.	No.	Min.	Avg.	Max.	No.	Min.	Avg.	Max.
10-17-64 thru 10-18-64												
LL-1.0	3	12	12.7	13	3	4.5	4.97	5.2	3	6.5	7.10	7.5
LL-2.0	3	12	12.7	13	3	3.7	4.70	5.3	3	5.7	7.23	9.6
LL-3.0	3	12	12.7	13	3	3.8	4.07	4.2	3	3.8	5.77	6.0
LL-4.0	3	13	13.0	13	3	3.6	4.23	4.7	3	3.6	5.77	5.9
LL-5.0	3	12	12.7	13	3	3.5	3.63	3.8	3	3.5	4.13	4.5
LL-6.0	3	12	12.3	13	3	4.2	4.57	5.0	3	4.2	3.83	4.1
LL-7.0	3	12	12.7	13	3	4.2	4.50	4.9	3	4.2	3.57	3.6
1-19-65 thru 4-1-65												
FC-3.0	3	-1	-0.3	0	3	8.8	10.90	12.7	3	1.2	3.77	6.9
CH-1.0	3	-1	-0.3	0	3	8.8	10.77	12.6	3	2.4	4.33	6.8
HM-0.2	3	0	0.3	1	3	10.1	11.33	12.5	3	2.4	3.10	3.6
MN-0.0	3	0	0.7	1	3	8.6	10.77	12.3	3	2.0	2.60	3.2
MN-2.0	3	0	0.7	1	3	9.9	11.23	12.5	3	4.2	5.40	6.4
NL-0.0	3	-1	0.0	1	3	10.4	11.27	12.3	3	2.0	4.17	6.1
NL-2.0	6	-1	0.7	0	6	8.3	9.83	11.2	6	3.5	4.10	5.2
NL-4.0	8	0	1.5	4	8	7.9	9.46	11.2	8	2.0	3.45	4.2
LL-1.0	5	-1	-0.8	0	5	8.5	10.18	11.7	4	3.6	5.45	5.0
LL-4.0	5	-1	-0.9	0	5	8.5	9.98	11.1	5	3.4	4.08	4.8
LL-7.0	4	-1	-0.5	0	4	8.3	9.78	11.5	4	3.3	3.55	4.0
LH-2.0	3	-1	0.3	2	3	11.5	12.10	12.9	2	5.4	--	7.4
HN-0.9	4	-1	1.0	4	4	11.3	11.98	12.9	3	5.0	5.70	7.0
HN-2.6	4	-1	1.2	4	4	10.9	11.38	12.5	3	4.1	5.90	7.0
HN-6.1	3	-1	0.3	2	3	9.5	10.50	12.2	2	5.0	--	8.0
6-21-65 thru 6-23-65												
FC-3.3	6	19	21.4	23	6	4.4	5.13	5.8	6	0.9	1.58	2.2
CH-0.0	6	19	21.4	23	6	4.7	5.20	6.0	6	1.8	2.08	2.3
CH-1.0	6	19	21.7	24	6	3.7	4.30	5.2	6	1.2	1.60	2.2
HM-0.2	6	21	22.4	24	6	4.3	4.63	5.3	6	1.3	1.70	2.2
HM-2.9	6	21	22.4	24	6	3.6	4.23	5.0	6	1.7	1.83	2.0
MN-2.0	8	21	22.0	23	8	4.2	4.71	5.4	8	2.2	3.49	5.0
MN-3.3	8	21	22.4	23	8	4.2	4.58	4.9	8	2.4	2.86	3.6
MN-4.0	8	21	22.4	24	8	4.0	4.55	5.3	8	2.2	2.66	3.3
NL-3.0	8	22	23.0	25	8	3.1	3.85	4.7	8	2.2	2.70	3.1
NL-3.4	4	23	23.5	26	4	3.3	4.20	6.4	4	1.9	2.60	2.9
NL-4.0	8	22	23.4	25	8	3.6	4.30	5.2	8	2.3	3.09	3.7

APPENDIX B (Continued)

TEMPERATURE, DISSOLVED OXYGEN, AND BIOCHEMICAL OXYGEN DEMAND

MERRIMACK RIVER

STATION	TEMPERATURE °C				DISSOLVED OXYGEN ppm				BOD_5 ppm			
	No.	Min.	Avg.	Max.	No.	Min.	Avg.	Max.	No.	Min.	Avg.	Max.
7-27-65 thru 8-3-65												
FC-3.3	26	20	22.5	25	25	4.2	5.24	6.5	13	0.9	1.18	1.7
CH-0.0	26	20	22.9	26	26	4.6	5.20	6.2	13	0.7	1.29	1.8
CH-0.6	26	20	22.9	26	26	4.4	5.16	5.9	13	1.0	1.62	2.0
CH-1.0	26	20	22.9	25	25	3.9	4.83	5.6	13	1.0	1.28	1.8
CH-1.1	5	23	23.2	24	5	4.3	4.84	5.1		--	--	--
CH-1.7	25	22	23.2	26	25	4.4	5.99	7.8	13	1.0	1.54	2.5
CH-2.1	10	23	26.2	30	16	4.8	6.28	8.5	9	1.2	1.71	2.4
CH-2.2	17	23	24.4	26	10	4.5	5.87	7.4	4	1.1	1.40	1.6
CH-2.9	25	22	23.6	26	25	5.0	6.42	9.3	13	1.0	1.72	2.7
HM-0.2	25	22	23.8	25	25	4.6	6.20	7.6	13	1.1	1.58	2.3
HM-0.6	25	22	23.6	26	26	4.4	6.00	7.6	13	1.0	1.42	2.0
HM-1.0	26	22	23.8	26	25	4.2	6.07	8.2	13	1.0	1.49	2.3
HM-1.4	26	22	23.6	25	26	4.2	5.77	7.3	13	0.8	1.28	2.0
HM-1.8	26	22	23.6	25	26	4.4	5.63	7.4	13	1.0	1.26	1.8
HM-2.3	26	22	23.6	25	26	4.7	5.93	7.9	13	0.9	1.52	2.8
HM-2.9	26	22	23.5	25	25	4.1	5.89	7.9	13	1.0	1.31	2.0
8-6-65 thru 8-13-65												
MN-0.0	26	22	23.9	26	26	4.8	5.67	6.9	13	1.1	2.03	2.9
MN-2.0	26	22	24.2	26	26	1.4	3.73	5.0	13	2.6	3.65	4.5
MN-2.6	26	22	24.2	27	26	2.1	3.19	5.0	13	2.1	3.34	4.9
MN-3.3	26	22	24.4	27	25	1.9	4.00	6.7	13	1.4	2.73	4.0
MN-4.0	26	22	24.4	27	26	2.6	4.69	7.5	13	2.3	3.15	4.0
MN-4.7	26	22	24.3	27	26	3.0	5.29	8.4	13	2.2	3.32	4.4
NL-1.0	26	22	24.3	26	26	2.2	4.67	6.7	13	3.0	4.32	5.9
NL-1.7	26	23	24.3	27	26	2.3	4.39	7.8	13	3.0	4.61	9.8
NL-2.0	26	23	24.3	26	26	2.5	5.10	9.3	13	2.4	4.80	7.7
NL-3.0	26	23	24.3	26	26	2.8	5.26	9.0	13	3.2	4.35	5.5
NL-3.5	26	23	24.3	27	26	2.4	5.73	9.7	13	3.9	5.00	6.2
NL-4.0	26	22	24.5	28	26	3.2	5.53	9.3	13	3.8	4.52	5.4

APPENDIX B (Continued)

TEMPERATURE, DISSOLVED OXYGEN, AND BIOCHEMICAL OXYGEN DEMAND

MERRIMACK RIVER

STATION	TEMPERATURE °C				DISSOLVED OXYGEN ppm				BOD_5 ppm			
	No.	Min.	Avg.	Max.	No.	Min.	Avg.	Max.	No.	Min.	Avg.	Max.
9-15-65 thru 9-16-65												
FC-3.3	2	18	--	18	2	3.6	--	3.9	--	--	--	--
CH-1.0	3	17	17.7	18	3	2.8	3.37	3.7	--	--	--	--
MN-0.0	6	18	19.3	20	6	2.4	2.92	3.7	2	1.3	--	2.4
MN-2.0	6	18	19.2	20	6	2.3	2.55	3.0	2	4.2	--	4.6
MN-2.6	4	18	18.8	19	4	1.7	2.25	2.7	2	2.5	--	2.5
MN-4.0	4	18	19.0	20	4	1.6	2.28	3.0	--	--	--	--
MN-4.7	4	18	18.2	19	4	1.7	2.12	2.6	2	1.8	--	2.0
NL-1.0	4	18	18.0	18	4	1.1	1.50	1.9	2	2.2	--	3.2
NL-1.7	4	18	18.0	18	4	1.1	1.65	2.1	--	--	--	--
NL-2.0	4	18	18.0	18	4	1.0	1.38	2.0	--	1.4	--	2.0
NL-3.0	6	18	18.2	19	6	1.2	1.32	1.7	--	--	--	--
NL-3.5	4	18	18.0	18	4	0.8	1.08	1.4	--	--	--	--
NL-4.0	6	18	18.5	20	6	0.8	1.25	1.6	2	1.1	--	1.2

APPENDIX B (Continued)

LONG TERM BOD RESULTS

All values in ppm

STATION	DATES SAMPLED	DAYS OF INCUBATION						
		2	3	4	5	7	10	15
FC-3.3	7/27-28/65	0.4	0.6	0.9	1.0	1.4	3.0	---
	7/28-29/65	0.6	0.8	0.9	1.2	1.4	3.4	---
CH-0.6	7/27-28/65	0.6	1.0	1.2	1.4	2.5	3.6	---
	7/28-29/65	1.0	1.3	1.4	1.9	2.4	3.2	---
HM-2.9	7/27-28/65	0.6	0.8	1.1	1.3	2.0	2.4	---
	7/28-29/65	0.7	1.1	1.3	1.7	2.2	2.8	---
MN-2.0	8/6-7/65	2.2	2.3	3.2	3.7	5.9	7.0	---
	8/11-12/65	2.2	2.4	3.2	3.4	4.4	5.6	---
MN-3.3	8/6-7/65	1.3	1.5	2.6	2.8	4.6	6.0	---
	8/11-12/65	1.5	1.7	1.9	2.3	2.5	4.6	---
MN-4.0	8/4-5/64	1.5	1.5	---	3.3	4.8	7.5	12.8
NL-1.0	8/4-5/64	2.0	3.0	---	4.0	5.8	9.5	17.5
NL-2.0	8/4-5/64	2.5	2.0	---	4.0	5.2	6.2	8.8
	9/17-18/65	0.6	1.0	1.5	1.8	2.5	5.2	---
NL-3.0	8/6-7/65	2.0	2.5	3.3	4.2	3.0	4.6	---
	8/11-12/65	2.0	2.1	3.0	3.6	4.5	8.8	---
LL-1.0	8/11-12/64	2.2	4.9	---	5.9	7.8	13.7	25.6
LL-4.0	8/12-13/64	1.5	1.8	---	3.1	5.5	10.8	10.0
LL-7.0	8/13-14/64	1.4	1.7	---	3.2	4.7	7.5	10.3
LH-2.0	8/26/64	3.0	3.7	---	6.2	8.3	9.7	22.0
HN-1.0	8/26/64	3.0	4.5	---	6.2	8.4	14.0	19.7

APPENDIX B (Continued)

NITROGEN AND PHOSPHATE RESULTS

MERRIMACK RIVER

STATION	DATE	NITROGEN						ORTHO PHOSPHATE mg/l as PO_4	
		AMMONIA mg/l as N		ORGANIC mg/l as N		NITRATE mg/l as N			
		No.	Avg.	No.	Avg.	No.	Avg.	No.	Avg.
MN-4.0	8/4/64-8/7/64	1	0.4	-	---	1	0.6	1	0.4
NL-1.0		5	0.4	-	---	1	0.8	1	0.4
NL-2.0		5	0.9	-	---	1	0.7	1	0.5
NL-4.0	8/11/64-8/14/64	3	1.1	-	---	-	---	-	---
LL-1.0		3	1.0	-	---	-	---	-	---
LL-7.0		3	0.9	-	---	-	---	-	---
NL-1.6	9/22/64-9/23/64	4	0.4	-	---	-	---	-	---
NL-1.7		4	0.5	-	---	-	---	-	---
FC-3.3	9/14-16/65	3	.47	3	.84	3	.3	3	.09
CH-1.0		3	.57	3	.75	3	.3	3	.15
MN-0.0		3	1.10	3	3.26	3	.2	3	.20
MN-2.0		3	1.40	3	3.36	3	.3	3	.84
NL-3.0		3	1.73	3	2.38	3	.5	3	.34
NL-1.7	10/7/65	1	3.5	-	---	-	---	-	---
FC-1.9	11/30/65-12/2/65	1	.24	1	.45	1	.16	3	.03
FC-3.3		1	.21	1	.43	1	.11	3	.02
CH-1.0		1	.16	1	.63	1	.10	3	.03
HM-0.2		1	.21	1	.63	1	.03	3	.03
HM-1.7		1	.10	1	.54	1	.14	3	.03
MN-2.0		1	.16	1	.81	1	.06	3	.10
MN-4.0		1	.09	1	.90	1	.12	3	.08
NL-3.0		1	.18	1	.54	1	.16	3	.19

APPENDIX C

SUMMARY OF COLIFORM DATA
SUMMER MONTHS
MERRIMACK RIVER

STATION	TIME OF TRAVEL, DAYS	NO. OF SAMPLES	TOTAL COLIFORMS/100 ml			FECAL COLIFORMS/100 ml		
			MIN	AVG	MAX	MIN	AVG	MAX
8-4-64 through 8-7-64 Method: MPN								
MN-4.0	--	17	17,200	81,600	160,000	1,100	18,600	92,000
NL-1.0	0.0	17	23,000	108,000	172,000	2,000	39,300	160,000
NL-2.0	0.7	16	17,200	67,000	160,000	2,000	14,600	27,800
NL-3.0	0.9	17	10,900	>58,900	>160,000	2,300	>21,300	>160,000
8-11-64 through 8-14-64 Method: MPN								
NL-4.0	--	10	7,000	15,100	34,800	200	2,500	4,900
LL-1.0	0.0	18	79,000	394,000	1,600,000	4,900	87,400	348,000
LL-2.0	0.2	9	130,000	406,000	920,000	33,000	59,200	109,000
LL-3.0	0.6	9	49,000	228,000	920,000	8,000	24,400	63,000
LL-4.0	0.9	9	14,100	79,100	160,000	2,300	11,800	54,200
LL-5.0	1.6	9	3,300	29,400	92,000	500	3,200	7,900
LL-6.0	2.0	9	4,900	10,900	24,000	200	1,540	3,480
LL-7.0	2.5	9	1,700	5,370	17,200	< 200	< 530	3,300
8-25-64 through 8-27-64 Method: MPN								
LH-1.0	0.1	12	490,000	1,910,000	9,200,000	40,000	213,000	542,000
LH-2.0	0.2	12	460,000	1,670,000	3,480,000	70,000	154,000	490,000
LH-3.0	0.7	12	79,000	605,000	1,600,000	23,000	83,200	130,000

APPENDIX C (Continued)

SUMMER MONTHS

STATION	TIME OF TRAVEL, DAYS	NO. OF SAMPLES	TOTAL COLIFORMS/100 ml			FECAL COLIFORMS/100 ml		
			MIN	AVG	MAX	MIN	AVG	MAX
8-25-64 through 8-28-64 Method: MPN								
HN-1.0	0.0	7	23,000	188,000	542,000	< 2,000	< 22,100	49,000
HN-2.0	0.4	7	46,000	238,000	920,000	2,000	21,000	49,000
HN-3.0	1.3	7	79,000	160,000	221,000	< 2	< 9,700	33,000
HN-4.0	2.3	7	4,600	141,000	348,000	< 200	< 1,700	2,300
HN-5.0	2.7	7	4,600	69,000	172,000	< 200	< 1,930	3,300
HN-6.0	3.5	7	490	41,500	160,000	50	1,590	5,420
6-21-65 through 6-23-65 Method: MF								
FC-3.3	--	6	900	1,750	3,600	110	315	570
CH-0.0	--	6	4,000	9,500	15,000	400	1,300	3,600
CH-1.0	--	6	4,000	5,500	7,000	600	870	1,480
HM-0.2	--	6	1,600	2,240	2,600	260	385	510
HM-2.9	--	6	750	1,330	2,100	95	260	576
MN-2.0	--	8	11,000	42,200	74,000	1,200	6,080	22,400
MN-3.3	--	8	6,000	15,200	24,000	400	950	2,170
MN-4.0	--	8	6,500	8,360	12,600	100	920	3,060
NL-3.0	--	8	3,800	8,040	24,000	400	680	1,040
NL-3.4	--	4	4,000	2,600	3,200	70	240	340
NL-4.0	--	8	1,000	10,700	54,000	84	270	990

APPENDIX C (Continued)

SUMMER MONTHS

STATION	TIME OF TRAVEL, DAYS	NO. OF SAMPLES	TOTAL COLIFORMS/100 ml MIN	TOTAL COLIFORMS/100 ml AVG	TOTAL COLIFORMS/100 ml MAX	FECAL COLIFORMS/100 ml MIN	FECAL COLIFORMS/100 ml AVG	FECAL COLIFORMS/100 ml MAX
7-27-65 through 8-3-65 Method: MF								
FC-3.3	--	24	< 400	< 1,730	4,600	< 10	< 459	2,500
CH-0.0	0.0	26	7,500	16,100	28,200	< 50	< 2,650	> 10,000
CH-0.6	0.6	26	11,000	26,300	57,000	1,100	4,560	9,800
CH-1.0	0.8	25	2,800	6,350	15,000	260	1,400	4,000
CH-1.7	1.7	25	1,200	4,020	10,600	80	670	2,200
CH-2.1	2.0	18	< 200	< 2,880	7,000	< 20	< 534	1,900
CH-2.2	2.1	8	3,600	4,720	5,600	280	652	1,060
CH-2.9	2.9	25	800	2,130	4,000	100	342	1,010
HM-0.2	3.0	25	1,000	2,060	3,600	130	367	1,080
HM-0.6	3.7	25	500	1,370	3,200	400	226	440
HM-1.0	4.2	26	300	854	1,450	25	152	425
HM-1.4	5.0	26	76	505	1,000	20	71	420
HM-1.8	5.5	26	100	272	700	10	39	140
HM-2.3	6.4	26	300	1,590	3,800	80	663	2,420
HM-2.9	6.8	26	1,100	2,660	5,200	80	869	3,340

APPENDIX C (Continued)

SUMMER MONTHS

STATION	TIME OF TRAVEL, DAYS	NO. OF SAMPLES	TOTAL COLIFORMS/100 ml			FECAL COLIFORMS/100 ml		
			MIN	AVG	MAX	MIN	AVG	MAX
8-6-65 through 8-12-65 Method: MF								
MN-0.0	--	26	700	3,960	7,900	20	703	3,140
MN-2.0	0.4	26	50,000	249,000	560,000	1,000	18,600	42,000
MN-2.6	0.7	26	9,000	31,000	82,000	600	3,960	15,000
MN-3.3	1.3	26	2,700	4,730	11,000	80	604	1,580
MN-4.0	1.8	26	1,400	4,880	12,600	100	> 391	> 2,000
MN-4.7	2.2	26	1,900	3,950	6,200	100	711	1,460
NL-1.0	0.0	26	10,000	48,700	84,000	5,800	> 15,100	> 60,000
NL-1.7	0.6	26	12,000	30,300	53,000	900	3,520	10,650
NL-2.0	0.8	25	6,000	15,000	31,000	530	1,740	6,000
NL-3.0	1.1	26	3,500	11,100	20,000	220	799	2,330
NL-3.5	1.5	26	200	2,780	5,700	140	361	980
NL-4.0	2.1	26	200	1,390	4,000	20	129	370

APPENDIX C (Continued)

SUMMARY OF COLIFORM DATA
WINTER, SPRING AND FALL MONTHS
MERRIMACK RIVER

STATION	TIME OF TRAVEL, DAYS	NO. OF SAMPLES	TOTAL COLIFORMS/100 ml			FECAL COLIFORMS/100 ml		
			MIN	AVG	MAX	MIN	AVG	MAX
1-19 through 4-1-65 Method: MPN								
FC-3.0	---	3	1,300	1,560	1,700	200	566	1,300
CH-1.0	---	3	7,900	20,000	34,800	2,200	3,470	4,900
HM-0.2	---	3	4,910	8,600	13,000	4,900	4,900	4,900
HM-2.9	---	3	5,420	6,680	9,200	1,720	2,900	3,500
MN-2.0	---	3	70,000	103,000	130,000	13,000	17,700	23,000
NL-0.0	---	3	17,200	48,000	92,000	4,900	12,300	2,400
NL-2.0	---	6	7,900	26,700	92,000	4,900	11,000	2,400
NL-3.0	---	1	---	13,000	---	---	4,900	---
NL-4.0	---	8	7,900	27,500	54,200	1,100	5,680	14,100
LL-1.0	---	5	49,000	85,000	109,000	13,000	17,000	21,000
LL-4.0	---	5	24,000	32,200	54,200	2,200	17,200	34,800
LL-7.0	---	5	13,000	43,200	92,000	3,300	7,820	13,000
LH-2.0	---	3	20,000	59,300	109,000	< 200	<14,100	31,000
HN-0.9	---	4	7,900	30,700	79,000	3,300	7,580	11,000
HN-2.6	---	4	22,000	58,200	109,000	400	12,800	33,000
HN-6.1	---	3	34,800	47,700	54,200	10,900	23,200	34,800

APPENDIX C (Continued)

WINTER, SPRING AND FALL MONTHS

STATION	TIME OF TRAVEL, DAYS	NO. OF SAMPLES	TOTAL COLIFORMS/100 ml			FECAL COLIFORMS/100 ml		
			MIN	AVG	MAX	MIN	AVG	MAX
5-11 through 19, 1965 Method: MPN								
FC-0.1	0.0	2	2,000	2,000	2,000	<2,000	<1,500	2,000
FC-0.3	0.1	2	2,300	2,800	3,300	500	1,400	2,300
FC-0.7	0.3	2	2,700	3,650	4,600	200	750	1,300
FC-1.2	0.4	2	1,700	3,300	4,900	200	500	800
FC-1.6	0.7	2	2,200	2,250	2,300	200	200	200
FC-1.9	0.9	2	1,300	4,600	7,900	<200	<400	700
FC-3.0	1.1	2	1,700	1,950	2,200	200	350	500
FC-3.3	1.4	2	2,600	2,950	3,300	200	350	500
FC-3.7	1.5	2	2,200	2,400	2,600	400	450	500
CH-0.0	0.0	2	22,000	27,500	33,000	2,000	7,500	13,000
CH-0.6	0.2	2	33,000	41,000	49,000	4,000	5,000	6,000
CH-1.0	0.3	2	17,000	43,500	70,000	4,000	4,500	5,000
CH-1.5	0.4	2	5,000	8,000	11,000	<2,000	<1,500	2,000
CH-1.7	0.5	2	3,300	10,000	17,200	200	800	1,400
CH-2.2	0.7	2	7,000	7,450	7,900	500	600	700
CH-2.9	0.8	2	4,900	9,000	13,000	200	500	800
HM-0.2	0.9	2	4,900	6,400	7,900	800	1,050	1,300
HM-0.6	1.1	2	4,900	9,000	13,000	2,300	2,300	2,300
HM-1.0	1.2	2	3,300	3,300	3,300	700	750	800
HM-1.4	1.4	2	4,600	10,900	17,200	800	950	1,100
HM-1.8	1.5	2	4,900	9,000	13,000	200	200	200
HM-2.3	1.6	2	2,300	3,600	4,900	200	350	500
HM-2.9	1.7	2	1,700	2,000	2,300	500	500	500
MN-1.0	0.0	2	23,000	150,000	278,000	21,000	22,000	23,000

APPENDIX C (Continued)

WINTER, SPRING AND FALL MONTHS

STATION	TIME OF TRAVEL, DAYS	NO. OF SAMPLES	TOTAL COLIFORMS/100 ml			FECAL COLIFORMS/100 ml		
			MIN	AVG	MAX	MIN	AVG	MAX
5-11 through 19, 1965		Method: MPN	(Continued)					
MN-1.3	0.1	2	80,000	80,000	80,000	< 20,000	<30,000	50,000
MN-1.7	0.1	2	50,000	60,000	70,000	< 20,000	<15,000	20,000
MN-2.0	0.2	2	20,000	45,000	70,000	< 20,000	<15,000	20,000
MN-2.5	0.3	2	50,000	270,000	490,000	< 20,000	<30,000	50,000
MN-2.7	0.4	2	20,000	29,500	49,000	4,000	< 7,000	20,000
MN-2.8	0.5	2	4,000	26,500	49,000	2,000	7,500	13,000
MN-3.4	0.6	2	17,000	25,000	33,000	5,000	5,000	5,000
MN-4.0	0.8	2	2,000	17,500	33,000	2,000	12,500	23,000
MN-4.4	0.9	2	9,000	21,000	33,000	<2,000	<4,500	8,000
MN-4.5	1.0	2	13,000	41,500	70,000	2,000	3,500	5,000
NL-0.0	0.0	2	130,000	865,000	1,600,000	< 20,000	<276,000	542,000
NL-1.0	0.1	2	8,000	69,000	130,000	4,000	4,500	5,000
NL-1.6	0.3	2	22,000	65,500	109,000	2,000	12,000	22,000
NL-1.7	0.4	2	8,000	69,000	130,000	< 2,000	< 4,500	8,000
NL-2.0	0.5	1	---	7,000	---	---	<2,000	---
NL-3.0	0.6	2	23,000	23,000	23,000	5,000	6,500	8,000
NL-3.2	0.7	2	23,000	36,000	49,000	<2,000	<3,000	5,000
NL-3.7	0.8	2	3,400	13,700	24,000	1,400	2,350	3,300
NL-4.0	0.9	2	4,900	19,850	34,800	200	6,500	13,000
NL-4.7	1.0	2	4,900	13,500	22,100	200	3,500	7,000
NL-5.3	1.1	2	4,900	4,900	4,900	700	1,500	2,300
LL-1.0	0.0	2	24,000	92,000	160,000	7,900	10,500	13,000
LL-2.0	0.1	2	17,000	88,500	160,000	2,000	6,500	10,900
LL-3.0	0.1	2	26,000	59,000	92,000	10,900	11,500	12,000
LL-4.0	0.2	2	23,000	>100,000	>160,000	5,000	11,100	17,200
LL-5.0	0.3	2	2,300	18,500	34,800	2,300	5,100	7,900

APPENDIX C (Continued)

WINTER, SPRING AND FALL MONTHS

STATION	TIME OF TRAVEL, DAYS	NO. OF SAMPLES	TOTAL COLIFORMS/100 ml			FECAL COLIFORMS/100 ml		
			MIN	AVG	MAX	MIN	AVG	MAX
5-11 through 19, 1965 Method: MPN (Continued)								
LL-6.0	0.5	2	7,900	21,400	34,800	2,200	2,250	2,300
LL-7.0	0.6	2	27,800	31,300	34,800	1,700	2,200	2,700
LL-8.0	0.9	2	10,900	10,900	10,900	200	2,400	4,600
LH-1.0	0.0	1	---	230,000	---	---	20,000	---
LH-2.0	0.1	1	---	90,000	---	---	20,000	---
LH-3.0	0.3	1	---	33,000	---	---	2,000	---
HN-0.0	0.4	1	---	253,000	---	---	6,000	---
HN-1.0	1.0	1	---	130,000	---	---	8,000	---
9-29 through 30-65 Method: MF								
MN-0.0	---	4	650	1,025	1,400	460	500	540
MN-2.0	0.3	4	20,000	35,000	60,000	1,000	8,600	16,600
MN-2.6	0.8	4	1,800	5,300	12,000	600	2,100	4,400
MN-3.3	1.4	4	1,700	5,220	9,000	1,700	3,420	5,000
MN-4.0	1.8	4	400	>1,980	>4,000	200	>1,900	>4,000
MN-4.7	2.3	4	600	1,880	4,000	100	562	1,410
NL-1.0	0.3	4	8,000	18,500	30,000	3,200	11,750	21,400
NL-1.7	0.9	4	4,300	8,200	11,000	3,100	4,880	6,300
NL-2.0	1.1	4	4,500	6,500	10,000	2,700	3,320	3,700
NL-3.0	1.4	4	1,200	3,680	6,000	1,200	2,300	3,700
NL-3.5	1.9	4	<1,000	<1,770	3,000	420	720	1,060
NL-4.0	2.4	4	420	738	1,000	<100	<312	530

APPENDIX C (Continued)

WINTER, SPRING AND FALL MONTHS

STATION	TIME OF TRAVEL, DAYS	NO. OF SAMPLES	TOTAL COLIFORMS/100 ml			FECAL COLIFORMS/100 ml		
			MIN	AVG	MAX	MIN	AVG	MAX
10-27 through 30-64 Method: MPN								
FC-0.1	0.0	2	13,000	52,500	92,000	1,300	18,050	34,800
FC-0.3	0.1	2	4,900	13,500	22,100	200	4,050	7,900
FC-1.2	1.1	2	1,090	1,750	2,400	130	135	140
FC-1.5	1.5	4	790	2,350	4,900	50	170	220
FC-1.9	2.0	2	330	4,750	9,200	50	570	1,090
FC-2.6	2.1	2	2,700	10,000	17,200	200	650	1,100
FC-3.0	2.2	2	1,700	7,350	13,000	200	350	500
FC-3.3	2.4	2	2,300	3,600	4,900	200	350	500
CH-0.0	0.0	2	24,000	24,400	34,800	7,900	12,550	17,200
CH-1.0	0.6	2	24,000	92,000	160,000	7,900	12,550	17,200
CH-1.3	---	1	---	92,000	---	---	13,000	---
CH-2.2	1.3	2	10,900	12,000	13,000	3,300	4,100	4,900
CH-2.7	---	1	---	17,200	---	---	3,300	---
HM-0.2	2.1	3	1,700	4,800	7,900	800	1,130	1,300
HM-0.6	---	1	---	24,000	---	---	800	---
HM-1.0	---	1	---	2,300	---	---	<200	---
HM-1.4	---	1	---	3,300	---	---	<200	---
HM-1.8	---	1	---	1,400	---	---	800	---
HM-2.0	---	1	---	700	---	---	<200	---
HM-2.9	4.7	3	1,090	2,100	3,480	310	377	490
MN-1.0	0.0	4	79,000	>1,220,000	>1,600,000	7,000	216,000	542,000
MN-2.0	0.4	2	109,000	850,000	1,600,000	33,000	722,000	1,410,000
MN-2.8	1.0	2	>160,000	>160,000	>160,000	17,200	20,600	24,000
MN-4.0	1.7	2	92,000	92,000	92,000	4,900	7,900	10,900
NL-2.5	0.0	2	24,000	92,000	160,000	4,900	6,400	7,900
NL-4.0	0.9	2	34,800	44,500	54,200	3,300	8,100	13,000

APPENDIX C (Continued)

WINTER, SPRING AND FALL MONTHS

STATION	TIME OF TRAVEL, DAYS	NO. OF SAMPLES	TOTAL COLIFORMS/100 ml			FECAL COLIFORMS /100 ml		
			MIN	AVG	MAX	MIN	AVG	MAX
11-15 through 19-65 Method: MPN								
HM-1.8	---	10	2,700	> 8,150	> 16,000	460	2,670	9,200
MN-1.3	0.0	10	14,000	127,000	172,000	2,000	26,600	54,200
MN-2.0	0.1	10	13,000	295,000	1,600,000	5,000	20,000	70,000
MN-2.6	0.3	10	11,000	60,000	240,000	4,900	9,600	23,000
MN-3.3	0.6	10	11,000	> 63,700	> 160,000	2,000	10,900	27,800
MN-4.0	0.8	10	17,200	72,000	160,000	3,300	9,000	24,000
MN-4.7	1.0	10	3,300	81,100	160,000	3,300	7,900	22,100
NL-1.0	0.2	10	17,200	> 64,300	> 160,000	3,300	18,200	54,200
NL-1.7	0.5	10	7,900	60,600	160,000	2,300	13,100	54,200
NL-3.0	0.8	10	17,200	55,000	92,000	3,300	14,000	54,200
NL-3.5	1.0	10	13,000	58,800	160,000	7,900	12,700	34,800
NL-4.0	1.2	10	13,000	27,900	54,200	2,300	6,900	10,900

APPENDIX C (Continued)

SUMMARY OF COLIFORM DATA
MERRIMACK RIVER ESTUARY

STATION	NO. OF SAMPLES	TOTAL COLIFORMS/100 ml MIN	TOTAL COLIFORMS/100 ml AVG	TOTAL COLIFORMS/100 ml MAX	FECAL COLIFORMS/100 ml MIN	FECAL COLIFORMS/100 ml AVG	FECAL COLIFORMS/100 ml MAX
9-15-64 through 9-16-64 Method: MPN							
R-1A	4	790	18,400	54,200	70	765	1,400
R-1B	4	< 20,000	< 560,000	1,720,000	< 20,000	148,000	330,000
R-2A	4	3,480	3,000	7,000	790	1,320	5,420
R-2B	4	1,100	5,360	7,900	< 200	< 1,570	3,300
R-2C	4	1,400	11,600	24,000	200	1,880	4,900
R-2D	4	1,300	18,300	34,800	490	< 5,700	17,000
R-2E	2	1,100	--	4,900	500	--	1,700
R-3A	4	50	5,160	16,000	< 20	< 560	1,720
R-3B	4	90	3,800	9,200	20	615	1,410
R-3C	4	230	2,190	5,420	50	648	1,720
R-3D	3	3,480	6,030	9,200	170	725	2,400
R-3E	2	2,400	--	3,480	490	--	1,300
R-3F	2	1,300	--	3,480	490	--	790
R-4A	4	2,700	3,720	5,420	200	772	1,300
R-4B	4	1,720	2,770	3,480	230	370	490
R-4C	1	--	5,420	--	--	1,090	--
R-5A	4	790	1,260	1,720	130	320	490
R-6A	4	490	2,000	5,420	70	255	490
R-6B	4	1,600	3,910	5,420	80	435	940
R-6C	4	110	690	1,720	< 20	< 65	170
R-6D	3	220	620	1,300	20	70	170
R-6E	2	170	--	1,300	< 20	--	1,300

APPENDIX C (Continued)

SUMMARY OF COLIFORM DATA
MERRIMACK RIVER ESTUARY

STATION	NO. OF SAMPLES	TOTAL COLIFORMS/100 ml			FECAL COLIFORMS/100 ml		
		MIN	AVG	MAX	MIN	AVG	MAX
10-19-64 through 10-20-64 Method: MPN							
R-1A	4	460	4,520	13,000	130	832	1,700
R-1B	4	< 20,000	< 1,540,000	5,420,000	< 20,000	< 522,000	1,720,000
R-2AA	4	< 20	6,000	22,100	< 20	< 680	1,400
R-2A	4	1,700	12,200	34,800	200	925	1,700
R-2B	4	1,400	5,080	10,900	200	1,200	3,300
R-2C	4	1,300	6,120	13,000	200	1,080	2,200
R-2D	4	< 2,000	48,600	109,000	200	< 16,100	49,000
R-2E	2	1,400	--	2,300	200	--	500
R-3AA	4	20	1,490	5,420	< 20	< 378	1,300
R-3A	4	< 20	5,370	16,000	< 20	< 870	1,720
R-3B	4	< 20	3,680	9,200	< 20	< 1,160	2,400
R-3C	4	490	5,590	9,200	330	1,680	5,420
R-3D	2	3,480	--	5,420	330	--	490
R-3E	2	9,200	--	9,200	490	--	1,300
R-3F	2	2,400	--	9,200	790	--	1,300
R-4A	4	< 200	3,860	13,000	110	< 952	3,300
R-4B	4	< 20	3,180	9,200	< 20	< 390	1,300
R-4C	2	20	--	70	< 20	--	< 20
R-5A	4	< 20	1,420	3,480	< 20	< 707	2,400
R-6A	4	40	815	2,400	20	132	230
R-6B	4	< 20	405	1,300	< 20	62	130
R-6C	4	50	232	490	20	80	170
R-6D	4	50	440	1,300	20	77	220
R-6E	4	170	422	700	< 20	< 48	110

APPENDIX C (Continued)

SUMMARY OF COLIFORM DATA
MERRIMACK RIVER ESTUARY

STATION	NO. OF SAMPLES	TOTAL COLIFORMS/100 ml			FECAL COLIFORMS/100 ml		
		MIN	AVG	MAX	MIN	AVG	MAX
6-8-65 through 6-10-65 Method: MF							
R-1A	6	1,000	< 5,170	10,000	< 10	< 3,700	< 10,000
R-1B	6	< 2,000	< 63,000	144,000	4,650	< 12,200	31,300
R-2AA	2	< 100	--	2,000	< 10	--	< 1,000
R-2A	6	200	3,220	6,800	< 10	< 390	< 1,000
R-2B	6	100	2,730	6,000	10	< 330	< 1,000
R-2C	6	< 100	< 3,180	8,600	< 10	< 252	< 1,000
R-2D	6	400	3,650	10,000	< 10	< 275	< 1,000
R-2E	2	200	--	< 1,000	< 10	--	< 1,000
R-3AA	4	100	625	1,900	< 10	< 38	100
R-3A	6	500	3,750	12,300	< 10	< 123	300
R-3B	6	506	3,000	8,800	< 10	< 105	340
R-3C	6	100	3,070	10,000	10	100	280
R-3D	5	< 100	< 2,420	5,200	< 10	< 98	300
R-3E	2	1,800	--	3,500	10	--	< 100
R-3F	2	1,100	--	1,200	40	--	300
R-4A	6	500	2,700	8,100	< 10	< 120	300
R-4B	6	100	3,080	7,800	< 10	< 115	400
R-4C	2	1,300	--	2,500	40	--	100
R-5A	6	80	2,510	8,200	10	101	280
R-6A	6	200	1,660	6,700	< 10	< 62	160

APPENDIX C (Continued)

SUMMARY OF COLIFORM DATA
MERRIMACK RIVER ESTUARY

STATION	NO. OF SAMPLES	TOTAL COLIFORMS/100 ml			FECAL COLIFORMS/100 ml		
		MIN	AVG	MAX	MIN	AVG	MAX
6-8-65 through 6-10-65 (Continued) Method: MF							
R-6B	6	100	2,080	11,600	10	33	100
R-6C	6	200	1,210	4,000	10	30	100
R-6D	4	100	3,560	13,400	10	27	100
R-6E	4	100	428	930	10	22	100
HN-6.0	6	5,000	5,470	11,000	40	333	1,000
HN-5.0	2	18,000	--	18,000	380	--	400
HN-4.0	2	15,000	--	82,000	200	--	1,450
HN-3.0	2	160,000	--	161,000	800	--	14,000
HN-2.0	2	190,000	--	290,000	5,000	--	13,800
HN-1.0	2	177,000	--	240,000	9,400	--	13,000
HN-0.0	2	130,000	--	200,000	8,000	--	12,400
LH-3.0	2	100,000	--	360,000	13,500	--	32,000
LH-2.0	2	100,000	--	2,030,000	28,800	--	186,000
LH-1.0	2	150,000	--	520,000	6,000	--	26,000

APPENDIX D

INDUSTRIAL WASTE RESULTS

MERRIMACK RIVER

STATION	RIVER MILE	SAMPLE OF	DATE	TEMP °C	FLOW	BOD_5 ppm	TSS mg/l	NH_3-N mg/l	PHENOL ug/l	PARA-CRESOL ug/l
HAMPSHIRE CHEMICAL CORP., NASHUA, NEW HAMPSHIRE										
NL-1.6	51.06	Effluent	8/6/64	--	---	--	--	2200		
---	51.04	River Mud	8/6/64	--	---	--	--	668		
---	51.12	River Water	9/22-23/64	--	---	--	--	0.5		
---	51.06	Brook Water	9/22-23/64	--	---	--	--	0.6		
NL-1.6	51.06	Brook Water	9/22-23/64	--	---	--	--	13.6		
---	51.04	River Water	9/22-23/64	--	---	--	--	2.4		
---	51.02	River Water	9/22-23/64	--	---	--	--	2.1		
---	51.00	River Water	9/22-23/64	--	---	--	--	2.1		
---	50.50	River Water	9/22-23/64	--	---	--	--	0.8		
NL-1.7	49.82	River Water	9/22-23/64	--	---	--	--	0.6		
NL-1.6	51.06	Brook Water	10/7/65	23	55 GPM	--	--	750		
---	51.06	Effluent #1	10/7/65	29	25 GPM	--	--	750		
---	51.06	Effluent #3	10/7/65	28	5 GPM	--	--	600		
NL-1.7	49.82	River Water	10/7/65	10	---	--	--	3.5		
NL-1.6	51.06	Brook Water	10/21/65	20	11 GPM	--	--	650		

APPENDIX D (Continued)

INDUSTRIAL WASTE RESULTS

STATION	RIVER MILE	SAMPLE OF	DATE	TEMP °C	FLOW	BOD_5 ppm	TSS mg/l	NH_3-N mg/l	PHENOL ug/l	PARA-CRESOL ug/l
NEW ENGLAND POLE AND WOOD TREATING CORP., MERRIMACK, NEW HAMPSHIRE										
---	61.85	River Water	10/7/65	9	---	--	--	---	9	0
MN-3.1	61.60	Effluent	10/7/65	61	3.5 CFS	--	--	---	400	0
MN-3.3	61.18	River Water	10/7/65	9	---	--	--	---	35	0
MN-3.3	61.18	River Mud	10/7/65	--	---	--	--	---	8000	0
NL-4.0	43.47	River Water	10/7/65	12	---	--	--	---	40	0
MN-3.1	61.60	Effluent	2/16/66	--	1 GPM	4200	240	---	--	--
FOSTER GRANT CO., MANCHESTER, NEW HAMPSHIRE										
MN-1.1	71.00	Effluent #1	12/2/65	--	---	7100	--			
MN-1.1	71.00	Effluent #2	12/2/65	--	---	13	--			
MN-1.1	71.00	Effluent #3	12/2/65	--	---	53	--			
MN-1.1	71.00	Effluent #1	2/16/66	--	0.8 CFS	2210	2			
MN-1.1	71.00	Effluent #2	2/16/66	--	0.4 CFS	21	2			
MN-1.1	71.00	Effluent #3	2/16/66	--	0.4 CFS	300	3			
FRENCH BROS. BEEF CO., HOOKSETT, NEW HAMPSHIRE										
---	80.55	Effluent	9/29/65	--	9.7 GPM	184	1240			

APPENDIX E

PHYSICAL, CHEMICAL, AND BACTERIAL DATA OF SELECTED TRIBUTARIES

STATION	DATE	NO. OF VALUES	TEMPERATURE °C			DISSOLVED OXYGEN ppm			BOD_5 ppm			TOTAL COLIFORMS/100 ml[1]			FECAL COLIFORMS/100 ml[1]			SOLUBLE PO_4-P mg/l	
			MIN.	AVG.	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.	MAX.	TOTAL	ORTHO
SOUHEGAN RIVER																			
So-9.0	10/28-30/64	2	--	--	--	--	--	--	--	--	--	270	--	700	20	--	170	--	--
So-9.0	5/12/65	1	--	--	--	--	--	--	--	--	--	--	5,420	--	--	310	--	--	--
So-8.6		1	--	--	--	--	--	--	--	--	--	--	7,900	--	--	800	--	--	--
So-8.0		1	--	--	--	--	--	--	--	--	--	--	4,900	--	--	1,300	--	--	--
So-7.0		1	--	--	--	--	--	--	--	--	--	--	7,900	--	--	200	--	--	--
So-3.0		1	--	--	--	--	--	--	--	--	--	--	2,000	--	--	< 2,000	--	--	--
So-2.0		1	--	--	--	--	--	--	--	--	--	--	220	--	--	50	--	--	--
So-9.0	5/27/65	3	--	--	--	--	--	--	--	2.0	--	340	510	700	20	50	110	--	--
So-8.6		3	--	--	--	--	--	--	--	2.1	--	2,100	3,970	4,900	400	530	700	--	--
So-8.0		3	--	--	--	--	--	--	--	2.2	--	3,300	7,670	13,000	200	700	1,700	--	--
So-7.0		3	--	--	--	--	--	--	--	2.0	--	7,000	12,800	17,200	1,300	3,200	4,900	--	--
So-6.0		3	--	--	--	--	--	--	--	3.2	--	23,000	111,000	240,000	2,000	15,300	33,000	--	--
So-5.0		3	--	--	--	--	--	--	--	3.0	--	79,000	113,000	130,000	8,000	16,300	33,000	--	--
So-3.8		3	--	--	--	--	--	--	--	2.3	--	17,000	21,000	23,000	<2,000	< 4,000	8,000	--	--
So-3.5		3	--	--	--	--	--	--	--	2.5	--	13,000	18,000	24,000	1,700	3,670	7,000	--	--
So-3.0		3	--	--	--	--	--	--	--	2.0	--	10,900	13,700	17,200	1,700	2,770	3,300	--	--
So-1.0		3	--	--	--	--	--	--	--	0.4	--	2,210	3,700	5,420	80	213	330	--	--
SB		3	--	--	--	--	--	--	--	0.9	--	170	530	1,090	80	170	220	--	--
So-9.0	8/6-13/65	26	20.0	23.8	26.0	6.4	7.73	10.1	1.0	1.82	6.2	400	332*	1,120	2	104*	1,120	--	--
So-9.0	9/17-18/65	4	17.0	17.0	17.0	8.8	9.15	9.5	--	--	--	--	--	--	--	--	--	--	--
NASHUA RIVER (for data other than at Station N-1.0 see part V of this report)																			
N-1.0	8/4-7/64	17	21.0	21.7	23.0	0.2	1.95	5.1	3.4	6.05	9.2	< 2	2,270	16,000	< 2	162	1,090	--	--
N-1.0	8/6-13/65	26	22.0	24.1	28.0	2.0	6.80	16.3	8.1	9.39	10.7	< 100	< 875*	5,100	< 2	> 66*	> 1,200	--	--
N-1.0	9/17-18/65	4	18.0	18.2	19.0	3.3	4.08	5.0	--	--	--	--	--	--	--	--	--	--	--
BEAVER BROOK																			
BB-5.0	11/17-18/64	2	--	--	--	--	--	--	--	--	--	220	--	490	20	--	50	--	--
BB-1.0	7/12-14/66	3	22.0	23.5	26.0	1.7	3.0	5.2	1.2	1.8	2.2	1,000	1,730*	3,200	40	190*	430	0.16	--
BB-2.0		3	20.0	21.7	24.5	2.0	2.7	4.1	1.0	1.7	2.2	1,200	4,200	8,000	80	390	720	0.21	--
BB-3.0		3	22.0	23.7	26.5	6.8	7.1	7.5	--	--	--	100	140	190	10	260	40	--	--
BB-4.0		3	22.0	23.3	25.0	5.4	5.8	6.3	--	--	--	190	560	1,300	70	190	400	--	--
BB-5.0		3	22.0	23.8	25.5	4.9	5.5	6.4	0.5	0.8	1.2	120	130	140	20	53	100	0.25	--
BB-6.0		3	24.0	24.8	27.0	4.4	5.4	6.3	0.8	1.0	1.3	1,900	3,760	7,400	300	530	770	0.51	--

[1] MPN unless first value starred (*) then MF.

APPENDIX E (Continued)

PHYSICAL, CHEMICAL, AND BACTERIAL DATA OF SELECTED TRIBUTARIES

STATION	DATE	NO. OF VALUES	TEMPERATURE °C MIN.	TEMPERATURE °C AVG.	TEMPERATURE °C MAX.	DISSOLVED OXYGEN ppm MIN.	DISSOLVED OXYGEN ppm AVG.	DISSOLVED OXYGEN ppm MAX.	BOD_5 ppm MIN.	BOD_5 ppm AVG.	BOD_5 ppm MAX.	TOTAL COLIFORMS/100 ml[1] MIN.	TOTAL COLIFORMS/100 ml[1] AVG.	TOTAL COLIFORMS/100 ml[1] MAX.	FECAL COLIFORMS/100 ml[1] MIN.	FECAL COLIFORMS/100 ml[1] AVG.	FECAL COLIFORMS/100 ml[1] MAX.	SOLUBLE PO_4-P mg/l TOTAL	SOLUBLE PO_4-P mg/l ORTHO
CONCORD RIVER																			
C-7.0	11/17-18/64	2	--	--	--	--	--	--	--	--	--	210	--	790	<20	--	20	--	--
C-8.0	5/12-13/65	2	--	--	--	--	--	--	--	--	--	2,300	--	13,000	200	--	500	--	--
C-1.0	6/28-30/66	6	24.0	24.9	25.5	4.4	4.8	5.4	0.6	0.8	1.1	240	410*	580	36	88*	130	1.03	0.86
C-2.0		6	24.0	25.2	26.0	4.3	5.2	5.9	0.3	0.7	1.3	220	290	400	44	71	110	0.93	0.75
C-3.0		6	24.0	25.1	26.0	3.6	4.4	5.7	0.8	0.9	1.0	90	180	250	20	43	88	0.90	0.68
C-5.0		6	28.0	26.1	24.5	3.7	6.6	8.8	1.5	2.3	3.6	20	80	200	4	9	20	0.78	0.59
C-6.0		6	24.0	25.4	27.0	2.5	4.6	7.0	--	--	--	--	80	--	--	12	--	--	--
C-7.0		6	24.0	26.1	28.5	3.9	5.5	7.4	1.1	1.4	1.6	60	120	200	20	28	44	0.69	0.54
C-8.0		6	23.5	25.8	27.5	1.3	2.9	4.5	2.1	3.1	4.6	13,000	20,000	35,000	5	250	750	0.83	0.68
C-9.0		6	24.0	26.3	27.0	1.3	2.9	5.2	1.8	2.6	3.4	2,000	22,100	46,000	5	501	900	0.97	0.72
ASSABET RIVER																			
A-0.5	6/21-23/66	6	16.5	19.9	24.5	6.9	7.20	7.8	0.4	0.8	1.1	1,100	3,680*	10,000	210	240*	260	0.06	0.04
A-1.0		6	18.5	21.2	25.5	1.3	2.50	3.1	6.0	7.4	8.2	360,000	517,000	730,000	63,000	102,000	180,000	5.29	4.99
A-2.0		6	19.0	21.2	24.0	0.1	0.40	0.8	5.1	5.6	6.1	3,200	89,200	240,000	100	5,220	16,000	6.41	5.26
A-3.0		6	20.0	21.8	23.5	1.7	3.28	4.9	3.4	3.9	4.2	1,400	4,800	7,600	50	80	120	6.52	2.61
A-3.5		6	20.5	22.2	23.5	4.5	4.80	5.0	--	--	--	--	--	--	--	--	--	--	--
A-4.0		6	20.5	21.9	24.5	2.7	3.30	4.8	1.7	2.8	3.7	2,000	10,320	28,000	80	130	240	2.82	2.38
A-4.5		6	19.0	22.1	24.0	6.1	7.90	9.3	--	--	--	--	--	--	--	--	--	--	--
A-5.0		6	21.5	23.9	26.0	4.3	5.30	7.3	3.3	3.0	4.2	160	730	1,800	10	40	60	1.24	1.06
A-6.0		6	21.0	23.5	25.0	5.3	7.40	9.5	1.4	3.6	4.8	640	2,120	4,700	150	240	330	0.43	0.30
A-7.0		6	22.0	24.2	27.0	5.2	6.30	6.9	2.8	3.7	4.7	400	2,700	9,000	40	70	140	1.38	1.20
A-8.0		6	22.0	23.8	26.0	3.0	4.40	7.6	1.6	1.8	2.0	100	160	300	10	25	44	0.83	0.66
A-9.0		6	21.5	24.3	26.5	7.2	7.50	7.8	1.3	1.8	2.3	3,800	6,300	8,200	960	1,810	4,600	0.70	0.58
A-9.5		6	22.0	23.8	25.0	6.3	6.60	6.9	3.5	3.8	4.4	1,200	4,020	5,500	360	600	990	1.13	1.10
A-9.8		6	20.5	24.0	26.0	6.7	8.40	9.9	1.6	1.6	1.7	870	2,880	7,300	110	365	930	0.76	0.77
A-9.8	6/28-30/66	6	22.5	24.6	26.0	3.5	4.20	4.7	0.6	1.7	3.5	200	490*	1,300	36	171*	350	1.04	0.89
SUDBURY RIVER																			
Su-1.0	6/28-30/66	6	25.0	26.8	29.0	5.5	6.8	7.2	0.7	1.2	1.7	200	770*	1,800	8	38*	60	0.12	0.04
Su-1.5		6	23.0	25.3	27.0	3.1	5.2	6.6	4.5	7.2	12.5	17,000	111,000	300,000	> 1,000	± 4,300	< 10,000	0.37	0.27
Su-2.0		6	23.0	25.4	27.5	3.5	6.3	7.5	2.1	8.9	15.0	15,000	>118,000	>340,000	>1,000	> 6,600	> 10,000	0.20	0.18
Su-3.0		6	23.0	25.2	27.0	4.3	6.2	7.9	0.2	0.7	1.1	3,000	55,600	190,000	> 50	> 30,900	100,000	0.24	0.12
Su-9.8		6	22.0	25.4	27.0	3.5	4.9	6.6	1.5	1.8	2.0	160	313	580	110	220	480	1.01	0.86
HOP BROOK (Sudbury River tributary)																			
HB-1.0	6/28-30/66	6	22.5	25.3	27.5	0.6	1.2	1.6	27.5	33.0	40.0	40,000	291,000*	1,100,000	< 1,000	± 11,900*	> 60,000	30.67	23.15
HB-2.0		6	24.5	26.8	29.0	3.0	3.1	3.4	17.5	19.0	21.5	1,900	5,320	10,000	220	< 547	< 1,000	19.40	15.28
HB-3.0		6	22.0	23.6	25.5	5.1	6.0	6.7	--	--	--	--	--	--	--	--	--	--	--

[1] MPN unless first value starred (*) then MF.

APPENDIX E (Continued)

PHYSICAL, CHEMICAL, AND BACTERIAL DATA OF SELECTED TRIBUTARIES

STATION	DATE	NO. OF VALUES	TEMPERATURE °C MIN.	AVG.	MAX.	DISSOLVED OXYGEN ppm MIN.	AVG.	MAX.	BOD_5 ppm MIN.	AVG.	MAX.	TOTAL COLIFORMS/100 ml[1] MIN.	AVG.	MAX.	FECAL COLIFORMS/100 ml[1] MIN.	AVG.	MAX.	SOLUBLE PO_4-P mg/l TOTAL	ORTHO
SPICKET RIVER																			
Sp-3.0	11/17-18/64	1	--	--	--	--	--	--	--	--	--	--	700	--	--	330	--	--	--
Sp-4.0			--	--	--	--	--	--	--	--	--	--	1,300	--	--	50	--	--	--
Sp-1.0	7/12-14/66	3	22.0	22.5	24.0	6.4	6.6	6.8	--	--	--	780	1,040*	1,300	520	710*	900	--	--
Sp-2.0			24.0	24.5	25.0	4.6	5.1	5.4	--	--	--	310	410	540	40	150	350	--	--
Sp-3.0			24.0	24.3	25.0	6.1	6.4	6.7	2.3	1.2	0.3	1,200	4,960	11,000	100	> 490	> 1,000	0.11	--
Sp-4.0			24.0	25.3	26.0	5.7	6.9	9.1	2.4	2.0	1.5	350	1,410	3,500	20	37	60	1.25	--
Sp-5.0			23.5	24.2	25.0	0.6	1.3	2.6	1.7	1.5	1.3	1,800	4,630	10,000	< 10	< 1,710	75,000	0.83	--
Sp-6.0			26.0	26.0	26.0	2.6	2.9	3.3	24.5	24.1	24.0	> 10,000	> 8,603,000	17,000,000	93,000	> 631,000	> 1,000,000	1.32	--
POLICY BROOK (Tributary of the Spicket River)																			
PB-3.0	11/18/64	1	--	--	--	--	--	--	--	--	--	--	9,200	--	--	110	--	--	--
PB-2.0	7/12-14/64	3	18.0	19.3	20.0	0.0	0.2	0.3	6.6	7.3	8.0	53,000	283,000*	730,000	5,700	> 39,200*	> 100,000	1.48	--
PB-3.0		3	22.0	22.8	23.5	0.7	3.1	6.4	2.5	2.9	3.1	2,000	24,700	58,000	200	1,570	4,000	0.80	--
SHAWSHEEN RIVER																			
Sh-6.0	11/17-18/64	2	--	--	--	--	--	--	--	--	--	2,210	--	2,210	170	--	790	--	--
Sh-9.0			--	--	--	--	--	--	--	--	--	1,720	--	5,420	1,300	--	1,720	--	--
Sh-1.0	7/18-20-66	6	20.0	23.3	27.0	4.0	7.9	11.1	--	--	--	1,800	12,000*	31,000	60	870*	2,400	--	--
Sh-2.0			20.0	22.8	26.0	2.1	5.4	8.0	1.2	1.6	2.3	700	10,800	53,000	< 100	638	2,200	0.11	--
Sh-3.0			20.0	22.3	25.0	0.8	3.5	6.4	1.3	1.6	1.9	200	950	1,500	40	77	130	0.43	--
Sh-4.0			19.5	22.3	25.0	1.6	4.5	7.9	1.2	1.5	1.7	300	1,020	2,200	24	43	60	0.17	--
Sh-5.0			19.0	21.9	24.5	3.8	7.2	10.6	1.2	1.5	2.1	330	910	2,200	40	67	70	0.18	--
Sh-6.0			19.0	22.5	25.5	3.6	6.5	10.5	0.9	1.1	1.3	900	5,520	17,000	80	135	190	0.56	--
Sh-7.0			20.0	23.8	26.5	0.7	1.6	2.7	2.5	3.1	3.7	60	2,130	4,500	< 4	< 9	20	0.93	--
Sh-8.0			20.0	23.3	25.5	1.4	3.3	6.3	1.1	1.1	1.2	5,000	48,300	190,000	70	> 1,080	> 5,000	1.07	--
Sh-9.0			20.0	25.4	29.0	5.2	7.5	9.1	1.1	1.8	2.6	1,700	> 5,130	> 10,000	250	> 2,740	> 10,000	0.60	--
Sh-10.0			22.5	25.0	27.0	5.7	7.1	8.1	1.7	2.2	3.1	5,300	11,100	22,000	220	830	1,800	1.06	--
Sh-11.0			20.5	24.7	28.0	6.3	8.1	9.9	--	--	--	4,500	9,520	19,000	190	560	1,100	--	--
Sh-12.0			23.0	24.7	27.5	6.7	10.3	13.5	2.8	3.4	4.0	2,600	8,000	> 18,000	120	1,120	2,000	0.21	--
LITTLE RIVER																			
L-3.5	11/17-18/64	2	--	--	--	--	--	--	--	--	--	460	--	490	20	--	20	--	--
L-1.0	7/12-14/66	3	19.5	21.6	23.5	7.8	7.9	8.1	--	--	--	380	1,370*	3,100	100	490*	1,100	--	--
L-2.0			22.0	22.7	24.0	5.0	5.4	6.1	--	--	--	390	2,250	5,600	110	360	650	--	--
L-3.0			21.5	22.2	23.5	4.5	5.4	6.0	1.3	1.5	1.7	62,000	78,600	89,000	140	620	900	0.18	--
L-4.0			24.0	24.7	25.5	4.1	6.5	8.9	--	--	--	660	2,950	4,900	60	340	720	--	--

1 MPN unless first value starred (*) then MF.

APPENDIX E (Continued)

PHYSICAL, CHEMICAL, AND BACTERIAL DATA OF SELECTED TRIBUTARIES

STATION	DATE	NO. OF VALUES	TEMPERATURE °C MIN.	AVG.	MAX.	DISSOLVED OXYGEN ppm MIN.	AVG.	MAX.	BOD_5 ppm MIN.	AVG.	MAX.	TOTAL COLIFORMS/100 ml[1] MIN.	AVG.	MAX.	FECAL COLIFORMS/100 ml[1] MIN.	AVG.	MAX.	SOLUBLE PO_4-P mg/l TOTAL	ORTHO
POWWOW RIVER																			
P-2.0	11/17-18/64	2	--	--	--	--	--	--	--	--	--	230	--	270	20	--	20	--	--
P-1.0	7/12-14/66	3	24.5	26.2	27.5	6.5	6.5	6.5	--	--	--	75	230	400	10	30	40	--	--
P-2.0			24.5	25.8	26.5	4.5	4.8	5.5	0.8	1.3	1.7	250	320	450	20	68	100	0.24	--
P-3.0			25.0	26.5	28.0	3.1	5.3	6.9	3.7	5.8	7.2	180,000	200,000	230,000	46,000	71,600	110,000	1.00	--
CONTOOCOOK RIVER at Riverhill Bridge, Concord, New Hampshire (River mile 100.71-4.2)																			
--	10/27-29/64	2	--	--	--	--	--	--	--	--	--	50	--	80	< 20	--	20	--	--
--	5/12-13/65	2	--	--	--	--	--	--	--	--	--	940	--	1,300	50	--	80	--	--
PISCATAQUOG RIVER at Grasmere Bridge, Goffstown, New Hampshire (River Mile 71.30-6.2)																			
--	10/27-29/64	2	--	--	--	--	--	--	--	--	--	460	--	490	< 20	--	< 20	--	--
--	5/12-13/65	2	--	--	--	--	--	--	--	--	--	140	--	2,210	< 20	--	20	--	--
SOUCOOK RIVER at Route 3 bridge and Route 106 bridge, Concord-Pembroke, New Hampshire (River Miles 85.80-3.5 and 85.80-6.4)																			
Rte. 3	10/27-29/64	2	--	--	--	--	--	--	--	--	--	< 20	--	790	< 20	--	70	--	--
Rte. 106	5/12-13/65	2	--	--	--	--	--	--	--	--	--	330	--	1,200	130	--	330	--	--
SUNCOOK RIVER 0.4 miles above Route 3 bridge and Route 28 bridge, Pembroke-Allenstown, New Hampshire (River Miles 82.90-1.5 and 82.90-5.2)																			
Rte. 3	10/27-29/64	2	--	--	--	--	--	--	--	--	--	1,300	--	1,720	170	--	490	--	--
Rte. 28	5/12-13/65	2	--	--	--	--	--	--	--	--	--	790	--	3,480	80	--	110	--	--

*MPN unless first value is starred (*) then MF.

APPENDIX F

NEW HAMPSHIRE WATER USE CLASSIFICATION AND QUALITY STANDARDS

	CLASS A	CLASS B		CLASS C	CLASS D
		B-1	B-2		
	Potentially acceptable for public water supply after disinfection. (Quality uniformly excellent.)	Acceptable for bathing and recreation, fish habitat and public water supply after adequate treatment. (High esthetic value.)	Acceptable for recreational boating, fish habitat, industrial and public water supplies after adequate treatment. (High esthetic value.)	Acceptable for recreational boating, fish habitat, and industrial water supply. (Third highest quality.)	Devoted to transportation of sewage or industrial waste without nuisance. (Lowest classification.)
Dissolved oxygen	Not less than 75% sat.	Not less than 75% sat.	Not less than 75% sat.	Not less than 5 ppm.	Present at all times.
Coliform bacteria MPN/100 ml.	Not more than 50.	Not more than 240.	Not more than 1,000.	Not specified.	Not specified.
pH	5.0 - 8.5.	5.0 - 8.5.	5.0 - 8.5.	5.0 - 8.5.	Not specified.
Substances potentially toxic	None.	Not in toxic concentrations or combinations.	Not in toxic concentrations or combinations.	Not in toxic concentrations or combinations.	Not in toxic concentrations or combinations.
Sludge deposits	None.	Not in objectionable amounts.	Not in objectionable amounts.	Not in objectionable amounts.	Not in objectionable amounts.
Oil and grease	None.	None	Not in objectionable amounts.	Not in objectionable amounts.	Not of unreasonable quantity or duration.
Color and turbidity	Not in objectionable amounts.	Not in objectionable amounts	Not in objectionable amounts.	Not in objectionable amounts.	Not of unreasonable quantity or duration.
Slick, odors and surface-floating solids	None.	None	Not in objectionable amounts.	Not in objectionable amounts.	Not of unreasonable quantity or duration.

NOTE: The waters in each classification shall satisfy all provisions of all lower classifications.

APPENDIX F

MASSACHUSETTS WATER USE CLASSIFICATION AND QUALITY STANDARDS

	CLASS A	CLASS B	CLASS C	CLASS D
	Suitable for any water use. Character uniformly excellent.	Suitable for bathing and recreation, irrigation and agricultural uses; good fish habitat; good aesthetic value. Acceptable for public water supply with filtration and disinfection.	Suitable for recreational boating, irrigation of crops not used for consumption without cooking; habitat for wildlife and common food and game fishes indigenous to the region; industrial cooling and most industrial process uses.	Suitable for transportation of sewage and industrial wastes without nuisance, and for power, navigation and certain industrial uses.
Standards of Quality				
Dissolved oxygen	Not less than 75% sat.	Not less than 75% sat.	Not less than 5 ppm	Present at all times
Oil and grease	None	No appreciable amount	Not objectionable	Not objectionable
Odor, scum, floating solids, or debris	None	None	None	Not objectionable
Sludge deposits	None	None	None	Not objectionable
Color and turbidity	None	Not objectionable	Not objectionable	Not objectionable
Phenols or other taste producing substances	None	None	None	
Substances potentially toxic	None	None	Not in toxic concentrations or combinations	Not in toxic concentrations or combinations
Free acids or alkalies	None	None	None	Not in objectionable amounts
Radioactivity	Within limits approved by the appropriate State agency with consideration of possible adverse effects in downstream waters from discharge of radioactive wastes; limits in a particular watershed to be resolved when necessary after consultation between States involved.			
Coliform bacteria	* Within limits approved by State Department of Health for uses involved.	Bacterial content of bathing waters shall meet limits approved by State Department of Health and acceptability will depend on sanitary survey.		

* Sea waters used for the taking of market shellfish shall not have a median coliform content in excess of 70 per 100 ml.

NOTE: Waters falling below these descriptions are considered as unsatisfactory and as Class E.
These standards do not apply to conditions brought about by natural causes.
For purpose of distinction as to use, waters used or proposed for public water supply shall be so designated.

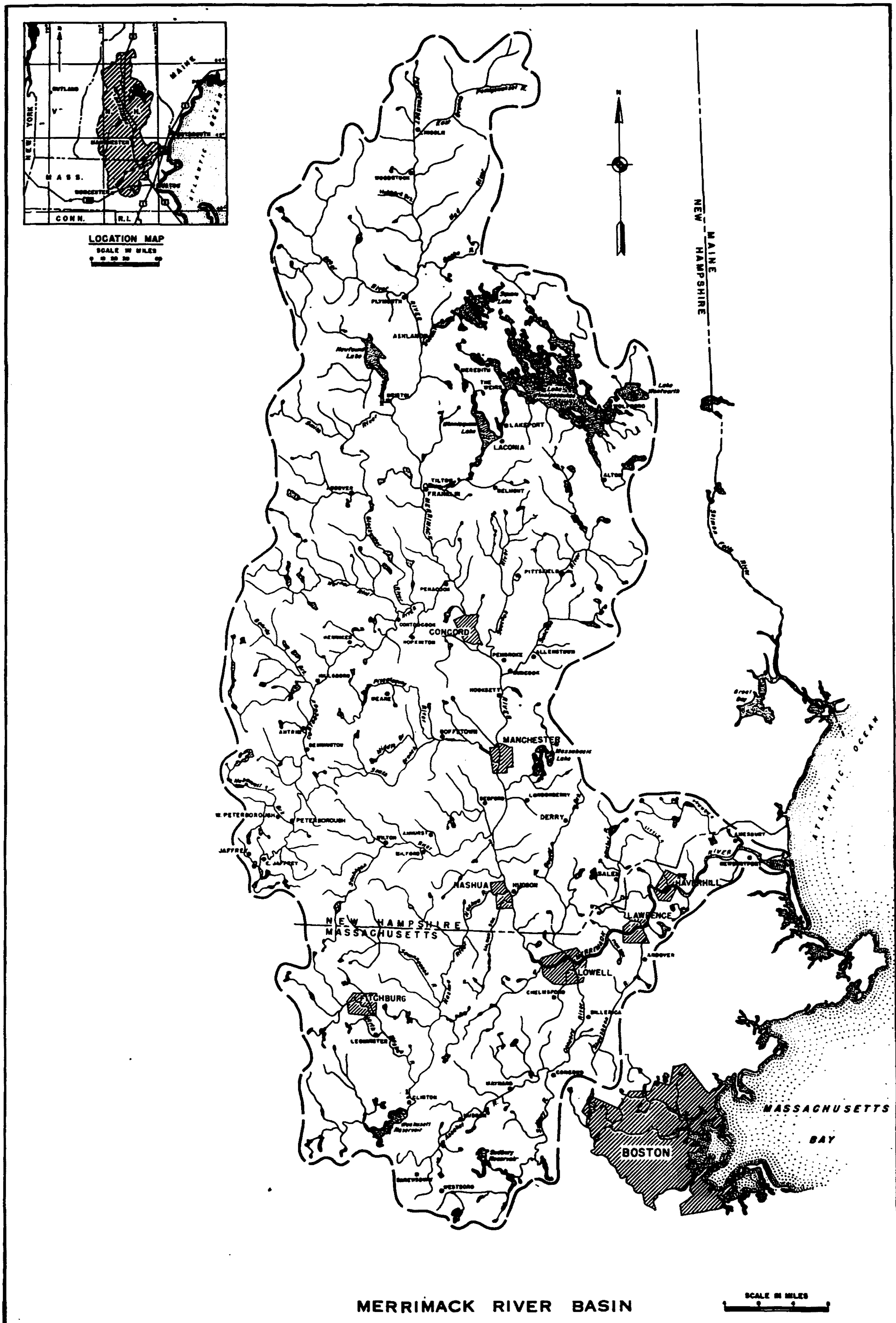
LOCATION MAP
SCALE IN MILES
MAINE
NEW HAMPSHIRE
LACONIA
CONCORD
MANCHESTER
DERRY
PETERBOROUGH
NASHUA
HAVERHILL
LAWRENCE
NEW HAMPSHIRE
MASSACHUSETTS
LOWELL
FITCHBURG
BOSTON
ATLANTIC OCEAN
MASSACHUSETTS
BAY
SCALE IN MILES
MERRIMACK RIVER BASIN

FIGURE 1